Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

1989

Parametric study of the aerothermodynamics of a jet engine test facility

Ratner, Todd G.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/27199

Downloaded from NPS Archive: Calhoun

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93943-5002

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

R24353

PARAMETRIC STUDY OF THE AEROTHERMODYNAMICS OF A JET ENGINE TEST FACILITY

by

Todd G. Ratner

March 1989

Thesis Advisor David Salinas

Approved for public release; distribution is unlimited.

T242279

REPORT DOCUMENTATION PAGE

Report Security Classification Unclassified	1b Restrictive Markings
Security Classification Authority Declassification Downgrading Schedule	3 Distribution Availability of Report Approved for public release; distribution is unlimited.
erforming Organization Report Number(s)	5 Monitoring Organization Report Number(s)
Name of Performing Organization aval Postgraduate School — 6b Office Symbol (*if applicable*) 34	7a Name of Monitoring Organization Naval Postgraduate School
Address (*city, state, and ZIP code*) onterey, CA 93943-5000	7b Address (*city, state, and ZIP code*) Monterey, CA 93943-5000
Name of Funding Sponsoring Organization — 8b Office Symbol (*if applicable*)	9 Procurement Instrument Identification Number
Address (*city, state, and ZIP code*)	10 Source of Funding Numbers

Program Element No	Project No	Task No	Work Unit Accession No

Title (*include security classification*) PARAMETRIC STUDY OF THE AEROTHERMODYNAMICS OF A JET ENGINE EST FACILITY

Personal Author(s) Todd G. Ratner

Type of Report	13b Time Covered	14 Date of Report (*year, month, day*)	15 Page Count
aster's Thesis	From To	March 1989	128

Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or poion of the Department of Defense or the U.S. Government.

Cosati Codes			18 Subject Terms (*continue on reverse if necessary and identify by block number*)
eld	Group	Subgroup	PHOENICS,Hush House,Test Cell,Aerothermal properties

Abstract (*continue on reverse if necessary and identify by block number*)

A three-dimensional numerical model of the Jet Engine Hush House located at Naval Air Station Jacksonville, Florida as developed using the PHOENICS computer code. The PHOENICS code was used to determine the steady state rothermal characteristics in the Hush House produced by a Navy F-4 (Phantom II) J-79-GE-8 gas turbine engine with terburner. The PHOENICS generated pressure, velocity, and temperature fields of the test cell facility based on the k-ε rbulence model are compared with results generated by a model incorporating a temperature dependent kinematic turbulent scosity. In addition, for the k-ε turbulence model, the effect of augmenter tube length on sytem behavior was investigated. essons learned and recommendations in obtaining a converged solution are included to aid in further applications of the HOENICS code.

0 Distribution Availability of Abstract ☒ unclassified unlimited ☐ same as report ☐ DTIC users	21 Abstract Security Classification Unclassified	
2a Name of Responsible Individual David Salinas	22b Telephone (*include Area code*) (408) 646-3426	22c Office Symbol 69Sa

D FORM 1473,84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

Approved for public release; distribution is unlimited.

Parametric Study of the
Aerothermodynamics of a Jet
Engine Test Facility

by

Todd G. Ratner
Lieutenant, United States Navy
B.S., University of Wisconsin, 1982

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1989

ABSTRACT

A three-dimensional numerical model of the Jet Engine Hush House located at Naval Air Station Jacksonville, Florida was developed using the PHOENICS computer code. The PHOENICS code was used to determine the steady state aerothermal characteristics in the Hush House produced by a Navy F-4 (Phantom II) J-79-GE-8 gas turbine engine with afterburner. The PHOENICS generated pressure, velocity, and temperature fields of the test cell facility based on the k-ε turbulence model are compared with results generated by a model incorporating a temperature dependent kinematic turbulent viscosity. In addition, for the k-ε turbulence model, the effect of augmenter tube length on sytem behavior was investigated. Lessons learned and recommendations in obtaining a converged solution are included to aid in further applications of the PHOENICS code.

Thesis
R24353
C.1

TABLE OF CONTENTS

I. INTRODUCTION 1

II. PROBLEM DESCRIPTION 4
  A. HUSH HOUSE CHARACTERIZATION 4
  B. ISSUES CONCERNING THE HUSH HOUSE 5

III. THE PHOENICS CODE 8
  A. GENERAL DESCRIPTION 8
  B. MODELING THE PROBLEM 11

IV. SOLUTION CONVERGENCE 22
  A. SOLUTION METHODS 22
  B. METHODS OF DETERMINING CONVERGENCE 23

V. USING THE PHOENICS CODE 31
  A. ALLOCATING MVS DATA SETS 31
  B. IMPLEMENTING GROUND 33
  C. DATA TRANSFER FROM MVS TO VAX 34

VI. COMPUTER MODEL RESULTS 37
  A. AUGMENTER TUBE LENGTH STUDY 37
  B. TURBULENCE STUDY 40

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
[illegible]

VII. CONCLUSIONS AND RECOMMENDATIONS 85

A. CONCLUSIONS 85

1. Augmenter Tube Length Study 85

2. Turbulence Study 85

B. RECOMMENDATIONS 86

APPENDIX A. "Q1" FILE (TURBULENCE STUDY) 88

APPENDIX B. PROGRAM FOR COPYING MVS DATA SETS 94

A. COPYTAPE 94

APPENDIX C. "GROUND" FILE (GROUP 9) 95

APPENDIX D. PROGRAMS REQUIRED FOR IMPLEMENTING GROUND 97

A. COPYGRD 97

B. COMPGRD 109

C. LINKEAR 109

APPENDIX E. PROGRAMS REQUIRED FOR COMPACTING FILES 110

A. PHOENX01 LOADLIB 110

B. PHOENX02 LOADLIB 110

C. PHOENX03 LOADLIB 110

D. PHOENX01 SOURCELB 111

E. PHOENX02 SOURCELB 111

F. PHOENX03 SOURCELB 111

APPENDIX F. PROGRAM "FORM09" 112

LIST OF REFERENCES 116

INITIAL DISTRIBUTION LIST 117

LIST OF TABLES

Table 1. DATA SET PARAMETERS 32

LIST OF FIGURES

Figure 1. Actual Hush House (Top Veiw Looking Down) 6
Figure 2. Actual Hush House (Side View) 7
Figure 3. Cell Faces 13
Figure 4. PHOENICS Flow Chart 14
Figure 5. Hush House Model (X-Z plane) 15
Figure 6. Hush House Model (Y-Z plane) 16
Figure 7. Temperature Profile for Original Hush House Model 17
Figure 8. Velocity Profile for Original Hush House Model 18
Figure 9. Sample Output Residuals vs Sweeps (Converging Solution) 28
Figure 10. Sample Output Residuals vs Sweep (Converging Solution) 29
Figure 11. Sample Output Residuals vs Sweeps (Diverging Solution) 30
Figure 12. Augmenter Tube Length Study Pressure Profile 43
Figure 13. Augmenter Tube Study Temperature Profile 44
Figure 14. Augmenter Tube Length Study Velocity Profile 45
Figure 15. Augmenter Tube Study Pressure Profile (normalized) 46
Figure 16. Augmenter Tube Study Temperature Profile (normalized) 47
Figure 17. Augmenter Tube Study Velocity Profile (normalized) 48
Figure 18. Velocity Vector Plot for Model 1 (test bay) 49
Figure 19. Velocity Vector Plots for model 2 (test bay) 50
Figure 20. Velocity Vector Plot for Model 1 (exhaust) 51
Figure 21. Velocity Vector Plot for Model 2 (exhaust) 52
Figure 22. Temperature Contour for Model 1 (augmenter tube) 53
Figure 23. Temperature Contour for Model 2 (augmenter tube) 54

Figure 24. Temperature Contour for Model 1 (exhaust) 55

Figure 25. Temperature Contour for Model 2 (exhaust) 56

Figure 26. Pressure Contour for Model 1 (augmenter tube) 57

Figure 27. Pressure Contour for Model 2 (augmenter tube) 58

Figure 28. Pressure Contour for Model 1 (exhaust) 59

Figure 29. Pressure Contour for Model 2 (exhaust) 60

Figure 30. Turbulence Study Temperature Profiles 61

Figure 31. Velocity Vector Plots for Model 3 (exhaust) 62

Figure 32. Velocity Vector Plot for Model 4 (exhaust) 63

Figure 33. Turbulence Study Pressure Profiles 64

Figure 34. Turbulence Study Velocity Profiles 65

Figure 35. Velocity Vector Plot for Model 3 (test bay) 66

Figure 36. Velocity Vector Plot for Model 4 (test bay) 67

Figure 37. Velocity Vector Plot for Model 5&6 (test bay) 68

Figure 38. Temperature Contours for Model 3 (engine exhaust) 69

Figure 39. Temperature Contours for Model 4 (engine exhaust) 70

Figure 40. Temperature Contours for Model 5&6 (engine exhaust) 71

Figure 41. Temperature Contours for Model 7 (engine exhaust) 72

Figure 42. Temperatuer Contours for Model 3 (exhaust) 73

Figure 43. Temperature Contours for Model 4 (exhaust) 74

Figure 44. Temperature Contours for Model 5&6 (exhaust) 75

Figure 45. Temperature Contours for Model 7 (exhaust) 76

Figure 46. Pressure Contours for Model 3 (engine exhaust) 77

Figure 47. Pressure Contours for Model 4 (engine exhaust) 78

Figure 48. Pressure Contours for Model 5&6 (engine exhaust) 79

Figure 49. Pressure Contours for Model 7 (engine exhaust) 80

Figure 50. Pressure Contours for Model 3 (exhaust) 81

Figure 51. Pressure Contours for Model 4 (exhaust) 82

Figure 52. Pressure Contours for Model 5&6 (exhaust) 83

Figure 53. Pressure Contour for Model 7 (exhaust) 84

I. INTRODUCTION

Todays sophisticated aircraft engines, both new and overhauled, require full operational testing prior to being placed in service. Jet engine test facilities are utilized to safely and effectively monitor aircraft and jet engine performance characteristics. In addition to providing an environment for acquiring test data, the test cells supply clean, distortion-free airflow to the engine inlet, decrease noise pollution by decreasing the kinetic energy of the jet, and cool the exhaust prior to exiting to the atmosphere [Ref. 1: p. 1].

There are five types of tests facilities currently used by the NAVY.

1. The Run-up Pad--where the aircraft is tied down in an unprotected environment to conduct power checks.
2. Sound Suppressors--equipment packages that reduce the noise of aircraft on the Run-Up Pad.
3. Open Test Stand (OTS)--outdoor engine test stand and portable sensing equipment.
4. Hush House--a total aircraft enclosure capable of around the clock testing.
5. Fully Enclosed Test Cell(TC)--an enclosed facility for complex testing of engines out of the airframe.

The run-up pad, sound suppressor, and the open test stand facilities although relatively inexpensive are highly inefficient and do not support military readiness needs. Noise and air pollution factors determine the allowable locations of the facilities and the environmental conditions control the time of operation of some of the facilities. The hush house and the fully enclosed test cell can operate independent from environmental conditions, and since noise is reduced, around the clock testing is allowed. [Ref. 2: p. 2]

As of March 1984, 75 Navy and Marine activities have 76 fully enclosed test cells and five hush houses. Only 60 out of the 76 test cells are fully operational. Most of the test cells are over 27 years old. Modern jet engines operate at much higher temperatures, mass flows, and velocities than they did 20 years ago when most of the test cells were designed and built. Due to the age of the facilities and high gas temperatures and water impingement, cracking and spalling of the test cell concrete walls continues to occur. In addition to the structural degradation of the test facilities many of the test cells are obsolete in that they are unable to support the increased size and wide variety of the engines requiring testing. [Ref 2: pp. 3-4]

Noise, air, and water pollution control at test facilities is under increasing scrutiny. Prior to 1976, military test cells were exempt from state and local regulations pursuant to section 233 of the Clean Air Act. The Federal Court decided in 1981, that jest engine test cells were to adhere to the requirements of the Clean Air Act. The absence and degradation of exsisting pollution control systems has increased the risk of physical injury to the test cell facility personnel as well as damage risk to test cells, equipment, and aircraft. In 1981, the Navy Environmental Health Center cited hearing loss and respiratory damage for $114 million with an anticipated claim growth of 9% each year. Equipment and aircraft are subjected to acoustic fatigue which could possibly shorten operating life. [Ref 2: p. 3]

It is the Navy's goal to provide standardized facilities for testing aircraft and aircraft jet engines that will incorporate the latest technology and which will adhere to all local, state, and federal regulations concerning environmental safety. The current jet engine test cell facilities were designed empirically, based upon the designer's experience and occasional aerothermal data obtained from existing test cells. The test cell facilities in general performed well for the type engines that they were designed for. Due to the increase in complexity and power of modern jet engines and aircraft the test cell facility design procedures of the past are inadequate. The design of a modern jet engine test facility must incorporate the effects of multiple engines producing nonconcentric flows, turbulence, supersonic velocities, extreme temperature gradients, and awkward geometries. In addition, the new test cells must be able to accomodate a wide variety of engines and aircraft each with its own characteristic exhaust temperature, exit velocity, and mass flow rate [Ref 1: p. 1].

The design of modern test cell facilities requires a more sophisticated design procedure. A numerical simulation of the test cell can provide the design engineer with critical performance data from existing test cells to aid in the design of new test cell facilities. The numerical model provides a cost and time efficient means of obtaining the performance data of existing test cell facility designs, and this information can be incorporated in the design of new test facilities.

The PHOENICS Code is used to numerically model the aerothermal characteristics in the Hush House Facility, located at Naval Air Station Jacksonville, Florida, due to the operation of a Navy J-79-GE-8 gas turbine engine.

II. PROBLEM DESCRIPTION

A. HUSH HOUSE CHARACTERIZATION

In 1980 the Air Force purchased 79 standardized demountable Hush Houses with test cell capabilities. The large scale purchase, standardized design, and simple contruction resulted in a relatively low cost of $2.2 million per Hush House. The Hush House located at Naval Air Station Jacksonville, Florida is of the same design as the Air Force Hush House except for the additional AFFF Firefighting system installed by the Navy. Neither the Air Force's nor the Navy's Hush House design incorporates air pollution control systems. Although the cost of the initial large scale purchase by the Air Force was low, the overall long term cost was significantly higher due to high maintenance repair costs. It appears that the purchase was made in haste and not fully researched. The Navy could benefit from a similar large scale purchase providing that a high performance low cost maintenance system can be designed. [Ref. 2: P. 1]

The basic operation of the Hush House consists of four major sections: intakes, test bay, augmenter tube, and exhaust stack as shown in Figure 1 on page 6 and Figure 2 on page 7. The primary intakes provide air for the gas turbine engine intake. The secondary intakes provide air to mix with the engine exhaust. The mixing of the low temperature low velocity secondary air with the high temperature high velocity exhaust results in cooling the hot exhaust gas and reducing the exhaust gas velocity. The test bay is a large unobstructed area where the entire aircraft or an engine mounted in a test stand is positioned for testing. The large test bay allows intake air to smooth out into a uniform profile prior to the engine intake thereby approximating true operating conditions. The augmenter tube is lined with acoustic absorption material to aid in acoustic energy dissipation from the engine and jet flow. The augmenter tube aids in the mixing of the engine exhaust and secondary intake cooling air. The exhaust stack changes the flow direction from horizontal to vertical as the exhaust gas flow exits to the atmosphere. [Ref. 1: p. 2]

The overall dimensions of the test bay are 28.7 meters (94 feet) wide by 25.5 meters (83.7 feet) long by 8.6 meters (28.2 feet) high. The 24.4 meter (76 feet) long oval shaped augmenter tube is centered at the rear end of the test bay with the floor of the tube at the same level as the test bay floor. The oval augmenter tube cross section is roughly 4.9 meters (16 feet) wide by 4.0 meters (13.2 feet) high. The dimensions are constant throughout the tube length. The exhaust stack at the end of the augmenter tube is simply a 45 degree ramp ending just short of the top of the augmenter tube. The exhaust opening is a 8.2 meter (27 feet) by 8.2 meter (27 feet) horizontal plane. The aircraft is positioned in the test bay with the engine outlet approximately 4.6 meters (15 feet) from the augmenter tube entrance (see Figure 1 on page 6 and Figure 2 on page 7). General operating procedures for conducting engine tests are described by Nicolaus (1988) [Ref. 3: pp. 5-6].

B. ISSUES CONCERNING THE HUSH HOUSE

The Air Force type Hush House in general is performing satisfactorily. Some structural and operational problems do exist in the Hush House. The stainless steel corrugated sheets that overlay the acoustic absorption material is subject to cracking along the welds. During long periods of idle engine operation a portion of the exhaust gas flow is deflected away from the augmenter tube entrance. The exhaust gas rises to the top of the test bay activating the high heat sensors [Ref. 3: p. 7]. Vibration of the entire Hush House structure is present during engine testing. It is not exactly clear what effect the vibration has on the structural integrity of the Hush Houses. Some of the Hush Houses require inspection and retightening of the bolts that fasten the acoustic absorption material to the walls of the augmenter tube [Ref. 2: p. 4].

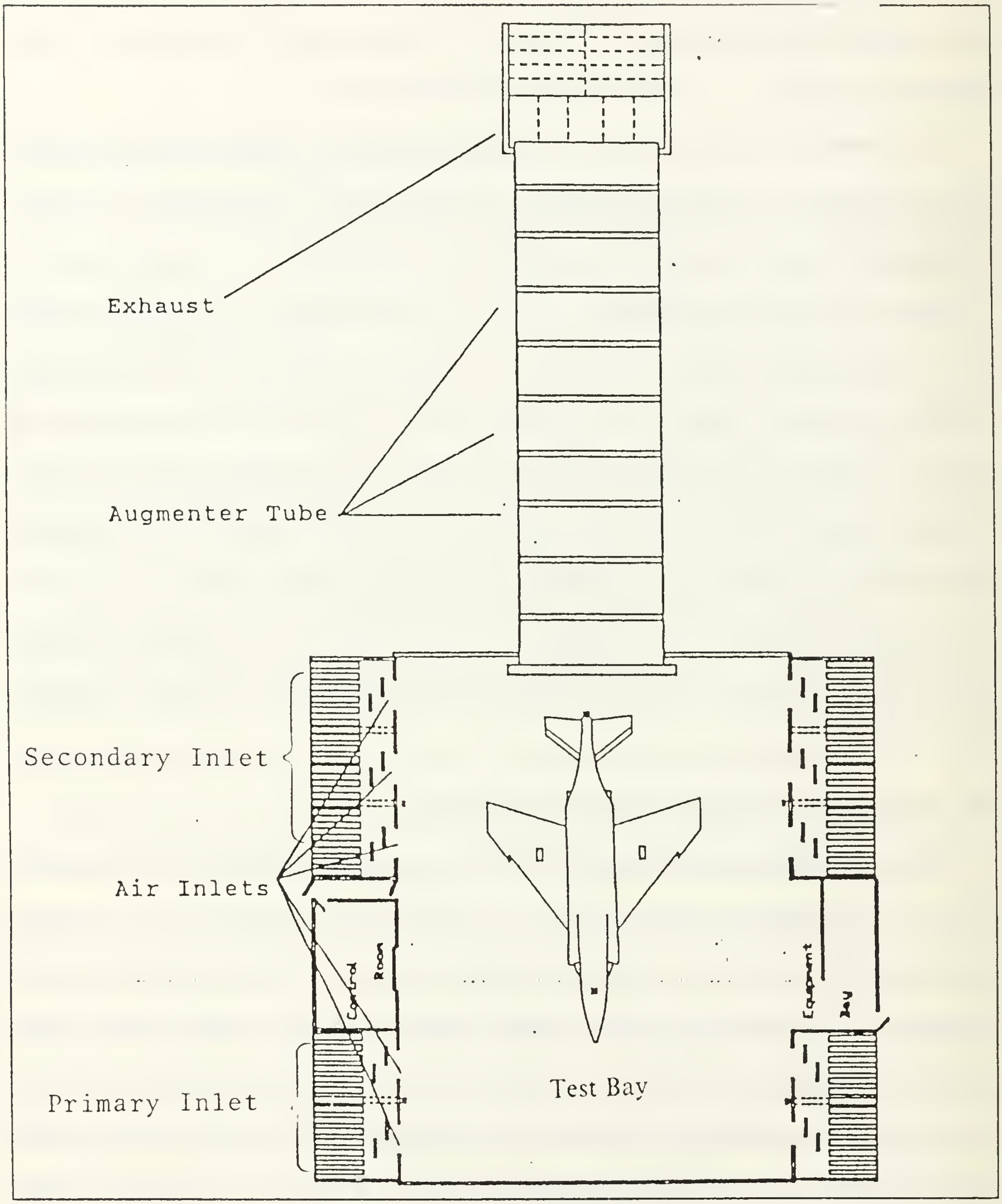

Figure 1. Actual Hush House (Top Veiw Looking Down)

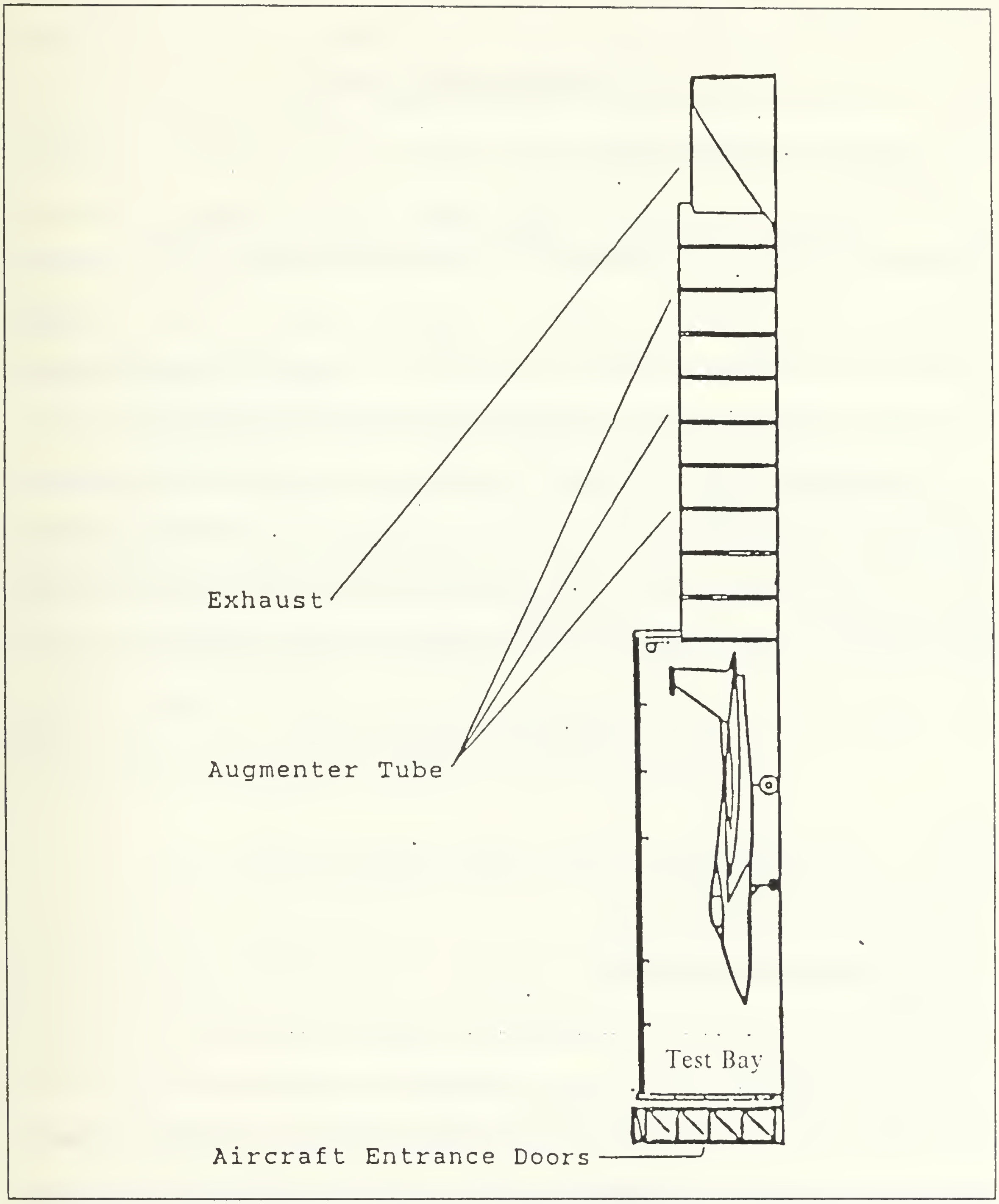

Figure 2. Actual Hush House (Side View)

III. THE PHOENICS CODE

A. GENERAL DESCRIPTION

PHOENICS is a commercially available general purpose computer program copy righted by CHAM (Concentration Heat and Momentum) Limited which was founded in 1972 by Prof. D. Brian Spalding of Imperial College in London, England. PHOENICS, an acronym for **P**arabolic **H**yperbolic **O**r **E**lliptic **N**umerical **I**ntegration **C**ode **S**eries, simulates fluid flow, heat transfer, and chemical reactions.[Ref. 4: p. 1.1]

The mathematical basis of PHOENICS is the iterative solution of descretized conservation equations of mass, chemical species, momentum, energy, turbulence quantities, and other related fluid properties. The general form of the conservation equation (before descretization) for which PHOENICS solves can be expressed in the form [Ref. 4: p. 6.2]:

$$\frac{\partial}{\partial t}(\rho\phi) + div\left(\rho\vec{V}\phi - \Gamma_{\phi} grad_{\phi}\right) = S_{\phi} \tag{3.1}$$

where:

$\phi \equiv$ dependent variable

$\Gamma_{\phi} \equiv$ exchange coefficient for ϕ

$S_{\phi} \equiv$ source of ϕ per unit volume

$\rho \equiv$ density

$\vec{V} \equiv$ velocity vector

For example, in the energy conservation equation the dependent variable ϕ would be enthalpy and the exchange coefficient Γ_{ϕ} would be the effective thermal conductivty divided by the constant pressure specific heat. The partial differential equations(p.d.e.) are coupled and nonlinear. The coupled, nonlinear conservation p.d.e's can only be solved (except for some very simple cases) by approximate numerical methods. Typical methods for their approximate numerical solution includes the finite difference and finite element methods. In the present case, the control volume method has features of both the finite difference and finite element methods. All these methods transform a partial differential equation into system of algebraic equations as follows:

$$a_p\phi_p = a_N\phi_N + a_S\phi_S + a_E\phi_E + a_W\phi_W + a_H\phi_H + a_L\phi_L + a_T\phi_T + b \tag{3.2}$$

where:

a ≡ influence coefficients

b ≡ a representation of the source of ϕ for the cell

The subscripts N, S, E, W, H, and L denote the North, South, East,West, High, and Low neighboring cell faces respectively as shown in Figure 3 on page 13. The subscript P denotes the grid node at a particular location and the T subscript denotes the same grid node at an earlier time. The system domain is partitioned into a grid network of cells. This partition discretizes the continous domain into N_c cells. Then each p.d.e. is transformed into an algebraic equation for each cell as follows:

$$\phi_p = \frac{a_N\phi_N + a_S + a_E\phi_E + a_W\phi_W + a_H\phi_H + a_L\phi_L + a_T\phi_T + S}{a_N + a_S + a_E + a_W + a_H + a_L + a_T + a_p} \tag{3.3}$$

Thus for example, the energy p.d.e. is transformed into N_c algebraic equations which are then solved for the value of enthalpy (or temperature) at the center of each of the N_c cells. It should be noted that these algebraic equations are also coupled, and therefore cannot be solved without solving the discretized algebraic equations for all of the dependent variables. The algebraic equations are numerous and dependent on similar equations from neighboring cells. The number of algebraic equations is equal to the number of dependent variables times the number of cells, N_c. The Hush House utilizes 4800 cells. Solving for seven dependent variables in each cell equates to the solution of

33600 equations. PHOENICS uses the SIMPLE algorithm requiring a guess and correction scheme of which the objective is to reduce the imbalance between the left and right hand sides of the discretized equation to a negligible magnitude [Ref. 5: p. 2.5]. The specific methods of reducing the imbalances (referred to as residuals) and thereby obtaining a converged solution is discussed in Chapter four.

The PHOENICS computer code consists of two main programs EARTH and SATELLITE. Figure 4 on page 14 shows the relationships between EARTH, SATELLITE, and their respective subprograms and hardware. The EARTH program is the largest of the two and it contains the coding for solving the conservation and related physical law equations. SATELLITE-EARTH communication is uni-directional, information can go only from SATELLITE to EARTH. Therefore a property which itself is a function of the solution, which is achieved in EARTH, cannot be accommodated by coding only in SATELLITE. For accommodating solution dependent properties, one must use GROUND. The subroutine GREX1 is an exemplary GROUND code that provides common options for general material properties such as density and viscosity. Desired options which are not in GREX1 must be programmed in GROUND.

The SATELLITE program transposes input data expressed in PHOENICS input language (PIL) into commands that will actvate EARTH. A Q1 file (quick-input file, number 1), where the flow problem is defined, is a formatted input file divided into 24 groups:

GROUP 1 ≡ Run title and other preliminaries
GROUP 2 ≡ Transcience: time-step specification
GROUP 3 ≡ X-direction grid specification
GROUP 4 ≡ Y-direction grid specification
GROUP 5 ≡ Z-direction grid specification
GROUP 6 ≡ Body-fitted coordinates or grid distortion
GROUP 7 ≡ Variables stored, solved and named
GROUP 8 ≡ Terms (in differential equations) and devices

GROUP 9 ≡ Properties of the medium (or media)
GROUP 10 ≡ Iterphase-transfer prosses and properties
GROUP 11 ≡ Initialization of variable or porosity fields
GROUP 12 ≡ Convection and diffusion adjustments
GROUP 13 ≡ Boundary conditions and special sources
GROUP 14 ≡ downstream pressure for PARAB = T
GROUP 15 ≡ Termination of sweeps
GROUP 16 ≡ Termination of iterations
GROUP 17 ≡ Underrelaxation devices
GROUP 18 ≡ Limits on variables or increments to them
GROUP 19 ≡ Data communication by SATELLITE to GROUND
GROUP 20 ≡ Preliminary printout
GROUP 21 ≡ Print out of variables
GROUP 22 ≡ Spot-value printout
GROUP 23 ≡ Field printout and plot control
GROUP 24 ≡ Dumps for restarts

A complete explanation of each group's data structure and a PHOENICS Input Language glossary can be found in the PHOENICS Beginners Guide and Users Manual (see Reference 2).

B. MODELING THE PROBLEM

The main scope of the thesis is a parametric study of the Naval Air Station, Jacksonville, Florida, Hush House originally modeled by Nicolaus in 1988 [Ref. 3]. The original model of the Hush House used the cartesian coordinate grid system of X, Y, and Z coordinates. The original three dimensional rectangular grid consisted of 40 cells in the Z direction (NZ = 40, low to high), 12 cells in the Y direction (NY = 12, south to north), and 10 cells in the X direction (NX = 10, west to east). The Hush House model takes advantage of the Y-Z plane of symmetry of the actual Hush House and therefore only half of the Hush House is modeled. Dividing the structure in half reduces the number of equations to be solved by half thereby reducing computer CPU time. The test bay is defined by cells 1-19 in the Z direction, cells 1-12 in the Y direction, and cells 1-9 in the X direction. The jet engine is defined by cells 12-14 in the Z direction, cells 4-5 in the Y direction, and cell 1 in the X direction. The augmenter tube is defined by cells 18-27 in the Z direction, cells 1-8 in the Y direction, and cells 1-5 in the X direction. The exhaust stack is defined by cells 28-39 in the Z direction , cells 1-8 in the Y direction, and cells 1-5 in the X direction. The 45 degree ramp at the end of the exhaust is modeled with a step system. Figure 5 on page 15 and Figure 6 on page 16 graphically display the X-Z and the Y-Z planes of the structure. [Ref. 3: pp. 25-26]

The graphical results of the temperature and velocity profiles at volume slab IX = 1 for IY = 4 from the original model shown in Figure 7 on page 17 and Figure 8 on page 18 indicate that the exhaust gas temperature and velocity were reduced by roughly 50 percent in the first 20 percent of the augmenter tube [Ref. 3: pp. 35-36]. The question then arose as to what would be the effect of a shorter augmenter tube. The first parametric study investigates the effects of augmenter tube length on the overall performance of the Hush House. Recall that the purpose of the augmenter tube is to reduce the exhaust gas temperature and velocity to an environmentely acceptable level prior to releasing the gas to the atmosphere. The performance of the Hush House is a function of the following parameters:

1. Condition of the flow field prior to entering the engine inlet
2. Magnitude of the mass flow rate of the secondary cooling air
3. Reduction of the gas temperature and velocity through the augmenter tube

The original augmenter tube length of 21.0 meters was reduced 10% to a length of 18.9 meters. The parametric study on the effects of augmenter tube length on system behavior used the same k- ε turbulence model as the original model. If the performance

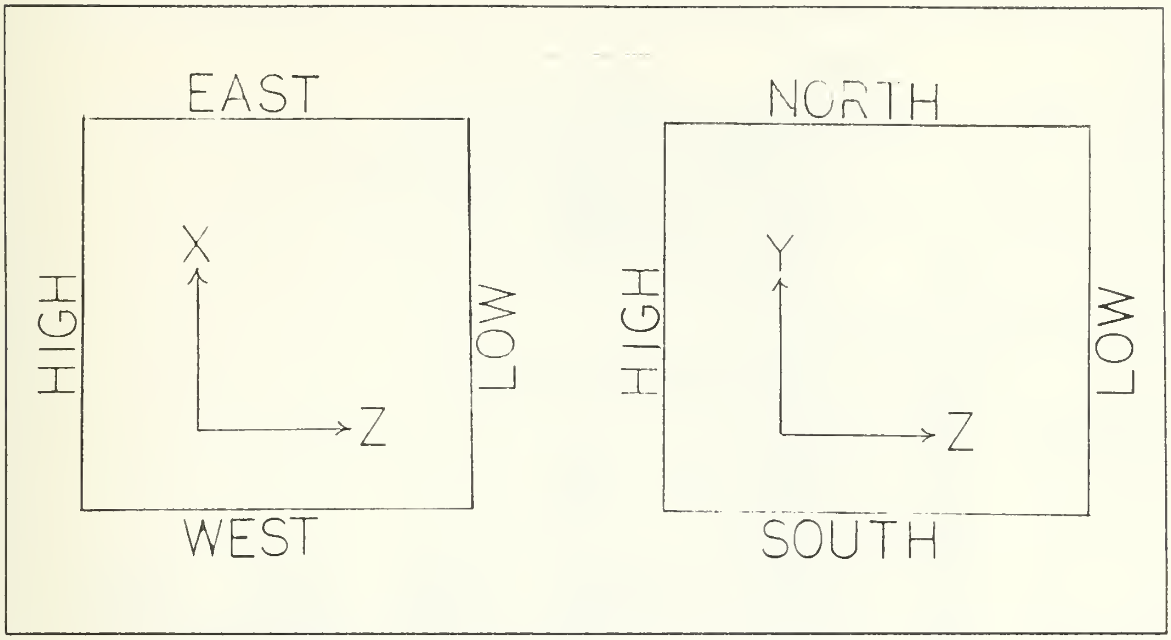

Figure 3. Cell Faces

of the Hush House was not significantly reduced by a shorter augmenter tube then the cost and time of construction, as well as the building size could be reduced.

Prior to conducting further geometrically based parametric studies the question arose of the effects that different turbulence models had on the aerothermal characteristics generated by PHOENICS. The concern is to know how dependent the pressure, velocity, and temperature fields were on turbulence modeling. The GREX1 subroutine offers the user of PHOENICS four turbulence models: [Ref. 4: p. 5]

1. Algebraic Model
2. Mixing Length Model
3. k-Mixing Length Model
4. k- ε Model

Gas flow through the Hush House is similar to flow through a three dimensional duct which is a wall boundary problem between two parallel Y-Z planes and two parallel X-Z planes. The Hush House model is actually much more complicated then just stated

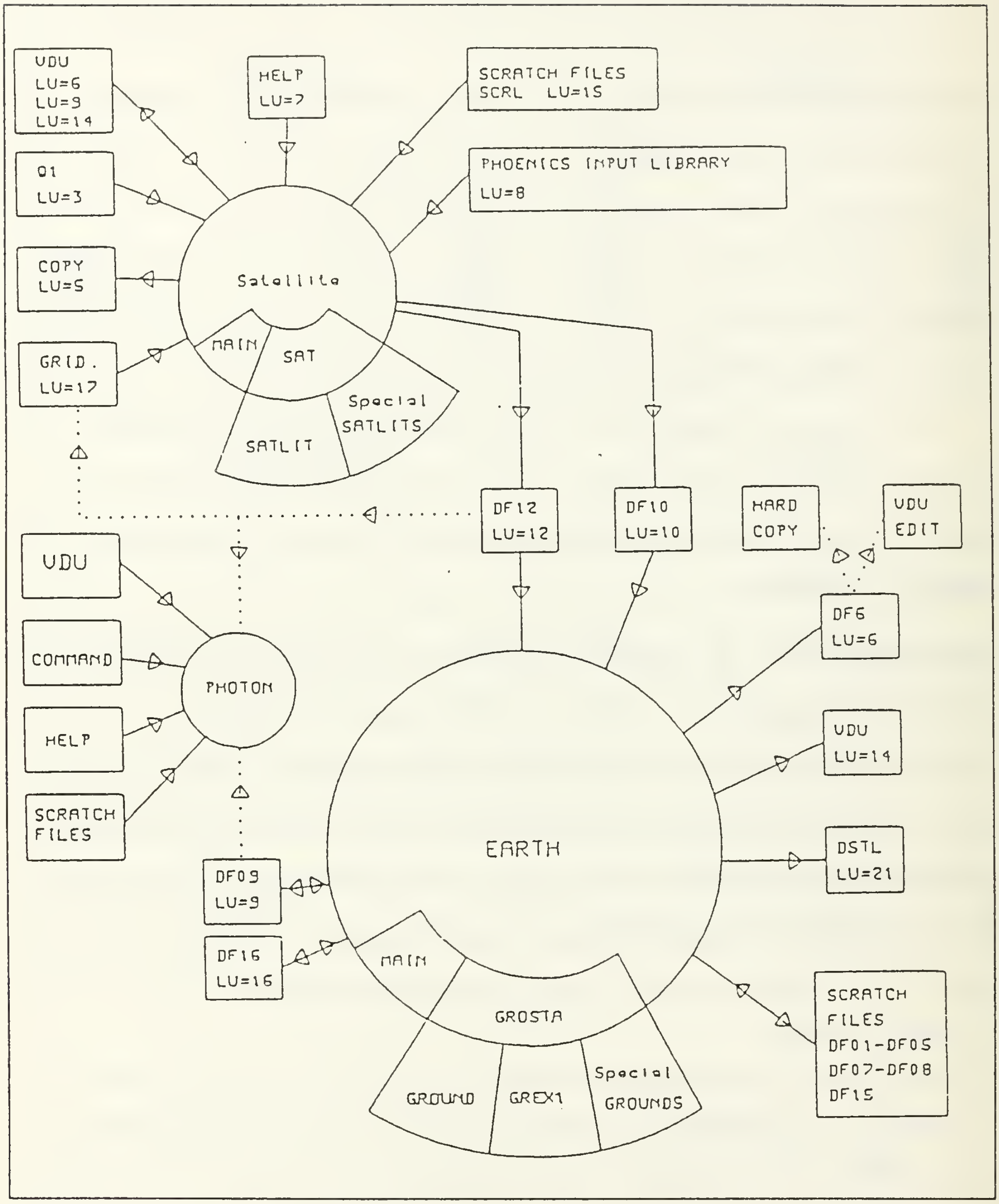

Figure 4. PHOENICS Flow Chart

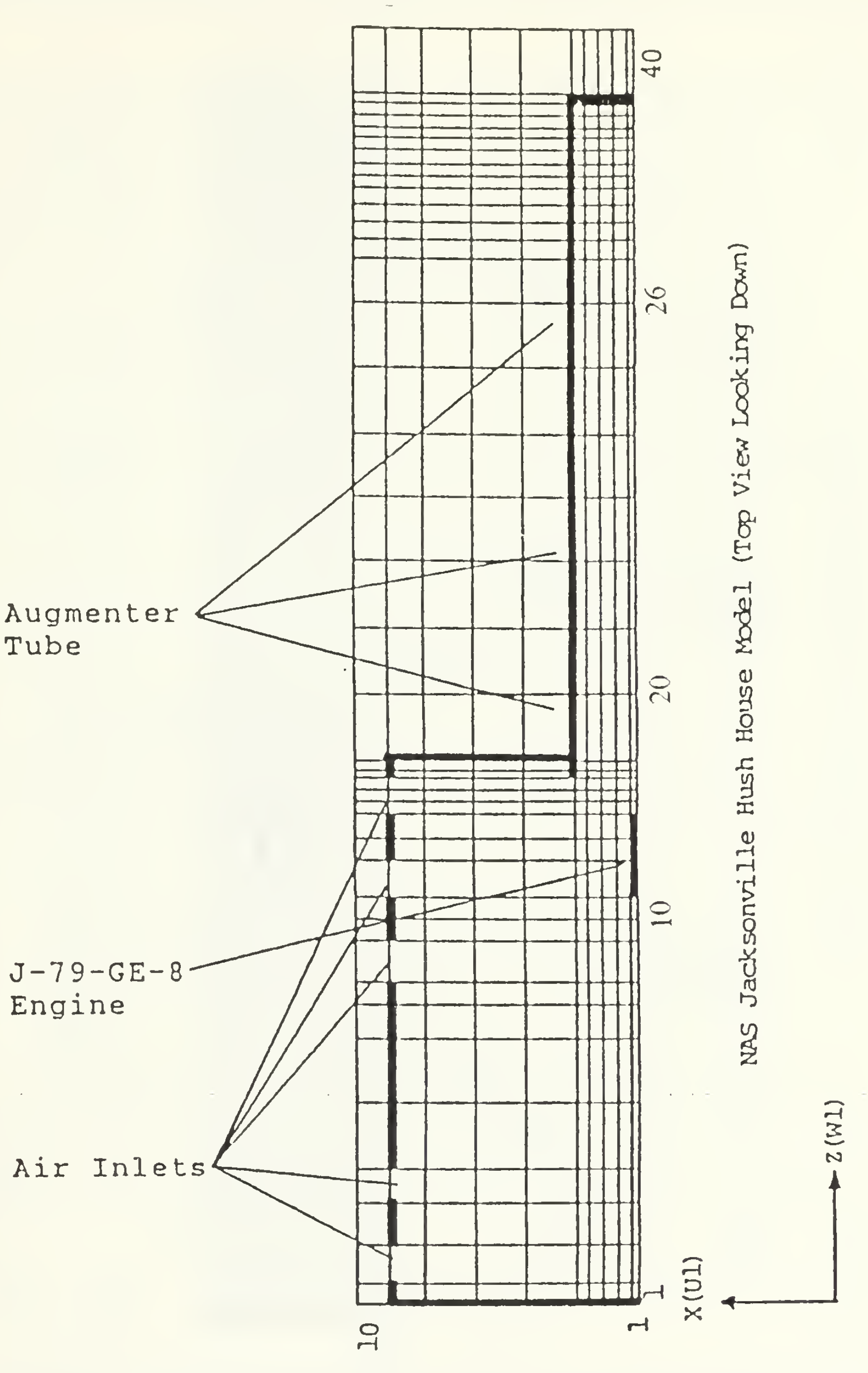

Figure 5. Hush House Model (X-Z plane)

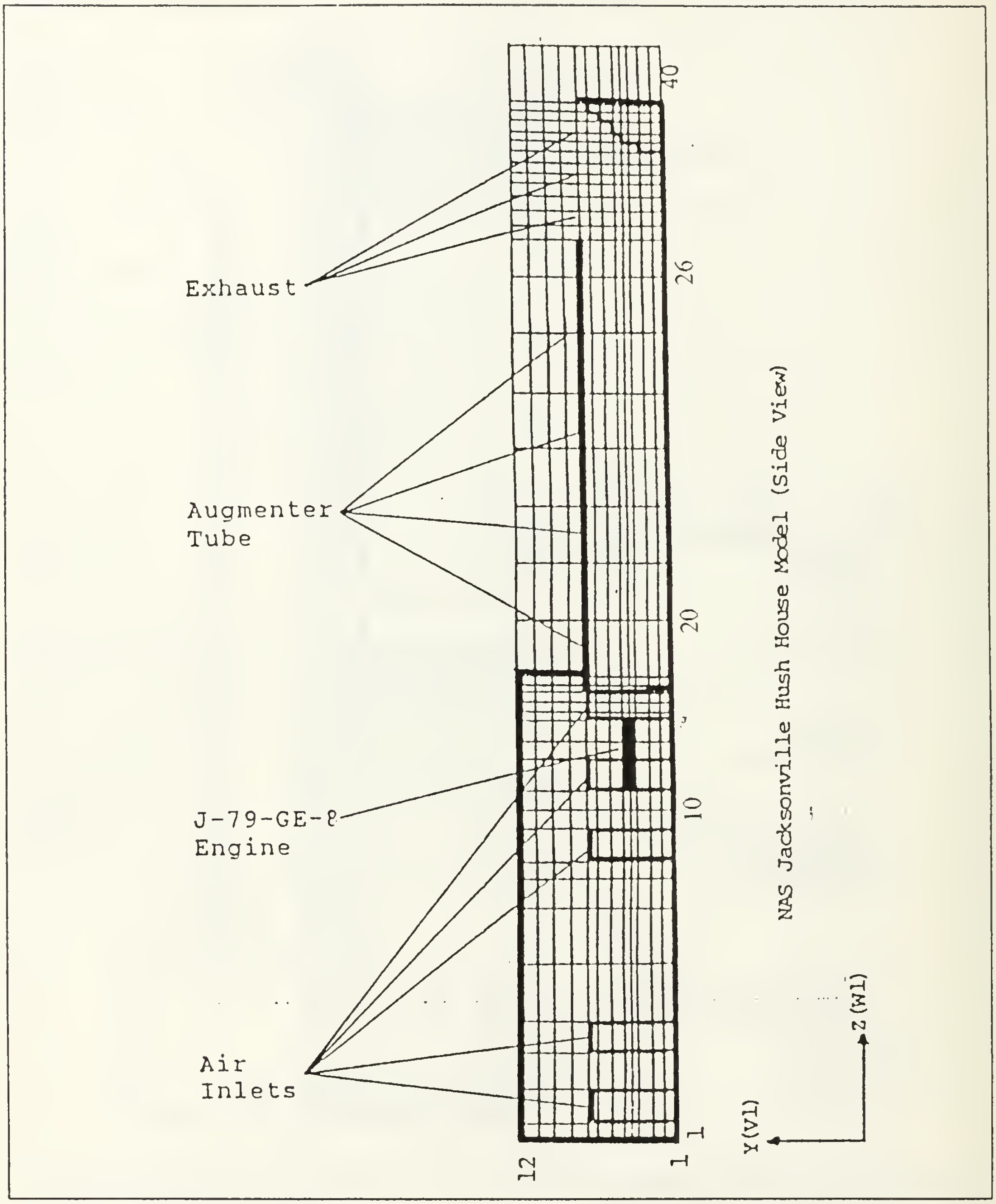

Figure 6. Hush House Model (Y-Z plane)

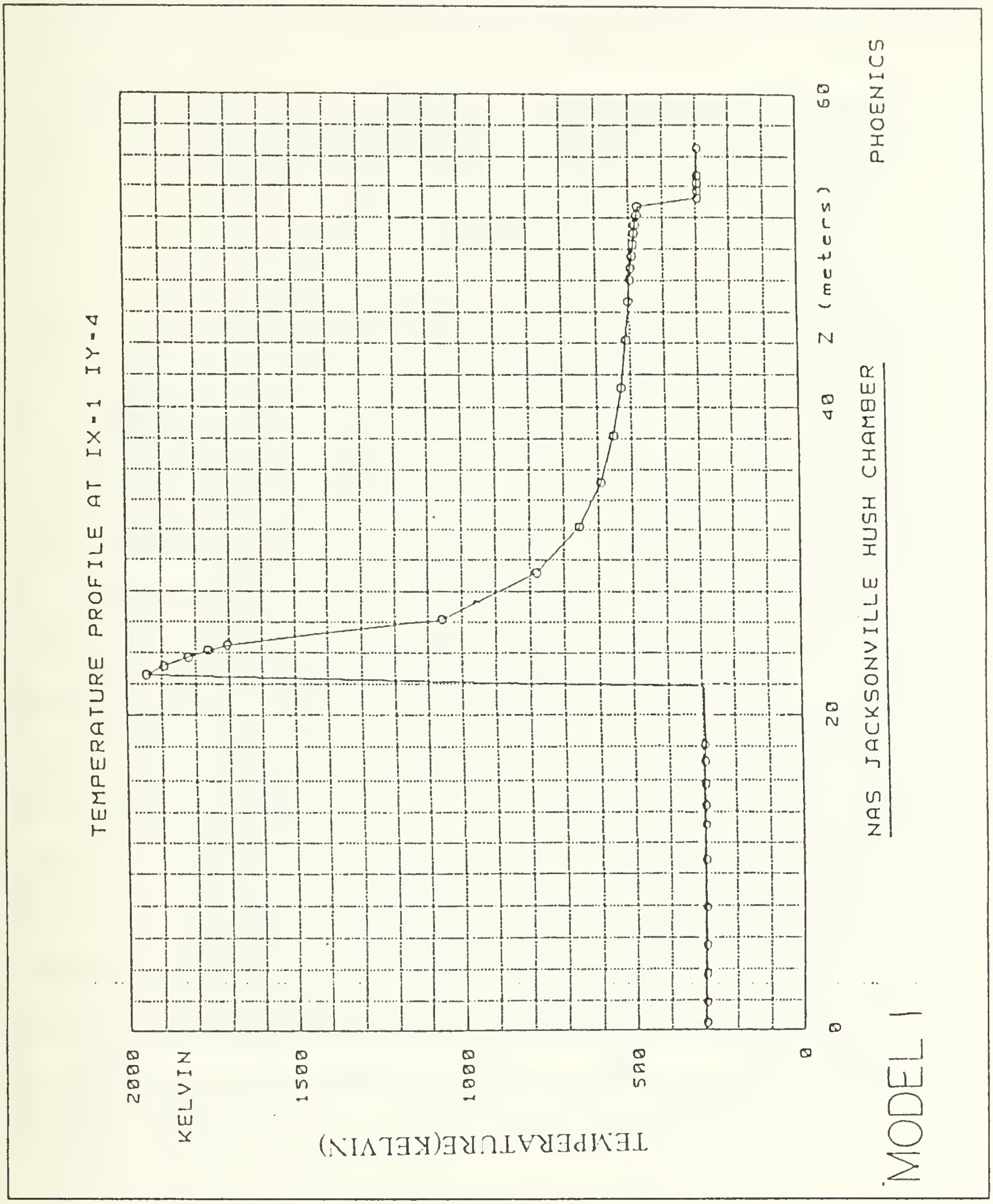

Figure 7. Temperature Profile for Original Hush House Model

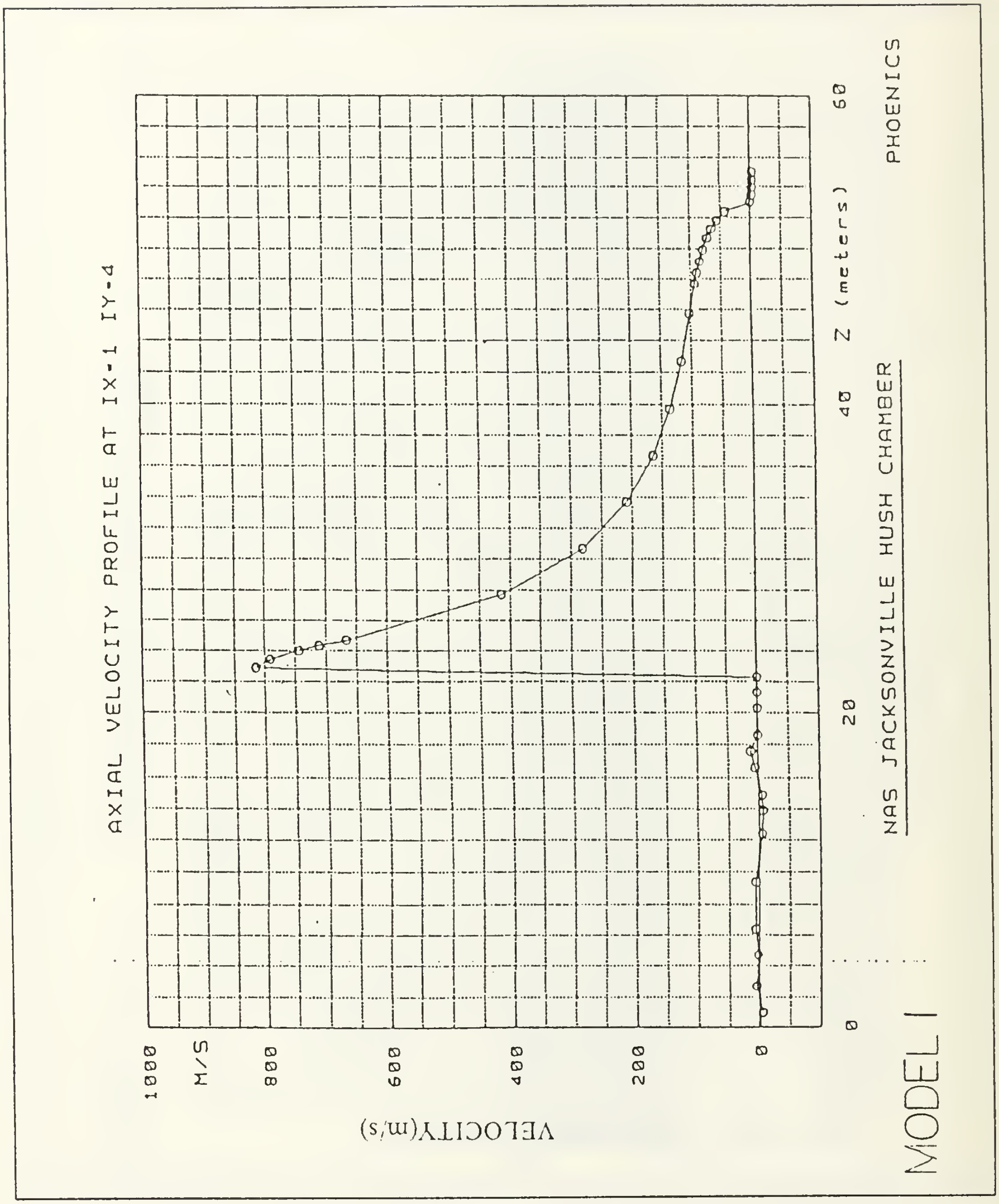

Figure 8. Velocity Profile for Original Hush House Model

but in attempting to select an existing turbulence model an assumption of the geometry configuration is required. The algebraic and mixing length models as coded in GREX1 are applicable to flow over a single flat plate and therefore are not suitable for this model. In the k-mixing length model turbulent viscosity is calculated according to:

$$v_t = C_u k^{0.5} l_m \tag{3.4}$$

where k, the turbulence kinetic energy is a dependent variable solved for by PHOENICS. C_U is a constant set in GREX1 and l_m is the mixing length. GREX1 has seven options for computing the mixing length l_m. The first three options, are applicable to flow over a single flat plate and are not suitable for the Hush House model. The fourth option selects the mixing length scale suitable for free jets. The Hush House has a wall bounded jet. The fifth option is suitable for free jets, but requires the setting of nine constants which can only be determined through experimentation of the specific flow system. The unavailability of these constants ruled this option out. The remaining two options select Nikuradse's mixing length scale which requires a cylindrical polar coordinate grid system for flow through a cylindrical duct. The k- ε turbulence model is the only PHOENICS model that is suitable for the Hush House without drastic changes to grid geometry. However, since the k- ε turbulence model was used originally and the other GREX1 turbulence options are unsuitable a turbulence model had to be developed and inserted into GROUND. A simple temperature dependent turbulent viscosity model was chosen because of the complex geometry involed. The turbulent viscosity term ENUT was set equal to a multiplying factor times the kinematic laminar viscosity ENUL.

$$ENUT = MF \times ENUL \tag{3.5}$$

ENUL (commonly referred to as v_l) is a function of the dynamic viscosity μ and the density ρ.

$$ENUL = \frac{\mu}{\rho} \tag{3.6}$$

The dynamic viscosity of air is temperature dependent over large temperature ranges.

$$\mu\left(295^{\circ} K\right) = 18.9 \times 10^{-6} \frac{Ns}{m^2} \tag{3.7}$$

$$\mu\left(2000^{\circ} K\right) = 62.27 \times 10^{-6} \frac{Ns}{m^2} \tag{3.8}$$

A fourth order polynomial equation for μ (T) was developed by Andrews and Biblarz in 1981 [Ref. 6: p.C-1].

$$\mu(T) = \left(x1 + x2 \times T + x3 \times T^2 + x4 \times T^3 + x5 \times T^4\right) \times 1.0 \times 10^{-6} \tag{3.9}$$

where:

x1 = 4.8856745

x2 = 5.43232×10^{-2}

x3 = $-2.4261775 \times 10^{-5}$

x4 = 7.9306×10^{-9}

x5 = -1.10398×10^{-12}

PHOENICS solves for the temperature and density of each cell therefore ENUT is temperature-density dependent and is not a constant value for each cell in the grid for any given multiplying factor,

$$ENUT = MF \times \frac{\mu(T)}{\rho} \tag{3.10}$$

The code line ENUT=GRND in group 9 of the Q1 file directs SATELLITE to the GROUND subroutine to evaluate ENUT for each cell. The code for evaluating ENUT is imbedded in group 9, section 6 of the GROUND subroutine enclosed in Appendix C.

The multiplying factor was arbitrarily selected as 200 initially and would be increased by 200 after convergence of each solution. This procedure would produce sets of pressure, velocity, and temperature fields that are based on different kinamatic turbulent viscosity values ranging from .0001 to 10 $\frac{Ns}{m^2}$. It was anticipated that for low values of kinematic turbulent viscosity the mixing effect of turbulence would be low and therefore the flow field would be highly streamlined. As the turbulent viscosity and mixing effect increased it was anticipated that the momentum transport between the exhaust gas and entrained cooling air would increase, resulting in lower velocities and temperatures exiting the exhaust stack.

IV. SOLUTION CONVERGENCE

A. SOLUTION METHODS

PHOENICS provides three methods for solving the NX x NY x NZ number of equations for each dependent variable:

1. Slabwise Method
2. Whole Field Method
3. Point-By-Point Method

A slab is an array of cells with the same value of low-to-high in the Z coordinate. In the Hush House model there are 40 slabs. The Slabwise method of solution solves for all the dependent variables in the lowest slab and then sequentially continues to the highest slab. The sequence of solving equations from low to high slabs is referred to as a sweep. The solution of the discretized equation for any dependent variable requires values from each neighboring cell. In the Slabwise solution the equations for values in a slab require values from the slabs below and above it. Adjustments to the values in the next higher slab will invalidate the values just solved for in the lower slab, therefore many sweeps are required until all the discretized equations balance and no further adjustments to neighboring cells are required. [Ref. 7: p. 2.5]

The Whole Field Method of solution simultaneously solves the NX x NY x NZ number of equations for each dependent variable in one sweep thereby reducing the number of sweeps compared with the Slabwise Method by a factor of NZ. The Whole Field Method requires much more computer storage space then the Slabwise Method and should not be used if storage space is limited. [Ref. 7: p. 2.5]

The Point-By-Point Method of solution does not employ PHOENICS simultaneous linear equation solver for the evaluation of the dependent variables. The node values of each variable are updated by simple arithmetic substitution. This simple substitution reduces the amount of computational work but requires many cycles to reach a final solution.

B. METHODS OF DETERMINING CONVERGENCE

A converged solution is one in which the imbalance between the left and right hand sides of every discretized equation is reduced to an acceptable small value. Due to the iterative procedure utilized by PHOENICS in solving the discretized equations, convergence is not guaranteed. User intervention is usually required to obtain a converged solution.

There are four means available to the user of PHOENICS to evaluate whether a solution is converging or diverging:

1. Tabulation of residuals vs sweep
2. Conservation of mass flow
3. Conservation of energy
4. Comparison of successive sweeps

Residuals calculated for each dependent variable are the sum of the absolute values of the discretized equation imbalance from each cell. The decrease in residuals with each successive sweep is the primary means of determining convergence. The output data file generated by PHOENICS provides the values of residuals vs sweeps for each dependent variable in tabular and graphical form. Figure 9 on page 28 show graphical examples indicating monotonic convergence. Monotonic convergence is characterized by sequential decrease of residuals vs sweeps. Monotonic convergence will usually, but not always, yield a final solution in the shortest amount of time. Monotonic convergence is not always possible or may be very difficult to obtain. Residuals may have a damped oscillatory decay as shown in Figure 10 on page 29. The computational time required to reach a converged solution with the residuals converging this way may be considerably greater than if monotonic convergence could be obtained. However a rapidly decreasing damped oscillatory decay can converge faster than o slowly decreasing monotonic decay. Divergence of a solution is determined by the residuals increasing with the number of sweeps as shown in Figure 11 on page 30. A diverging solution if unaltered will most likely result in "self destruction" of the simulation.

There are no cut and dry methods for obtaining and maintaining a converged solution. The general guidelines for obtaining a converged solution are discussed in part 2 section 8 of Reference 7. In choosing a viable set of convergence control options from the large number of possibilities, the PHOENICS programmer must use common sense, experience, and trial and error.

Three convergence control options were utilized in the Hush House model:

1. Under relaxation factor
2. Termination criteria for inner iterations
3. Incrementation of source terms

The under relaxation factor controls the rate of change of a dependent variable from sweep to sweep. Due to the iterative procedure utilized by PHOENICS, improper setting of the under relaxation factor of a dependent variable can result in a diverging solution. Under relaxation factors range from just greater than zero to one. Small values of the under relaxation factor require more iterations for convergence to be obtained and thus more computer time to reach a final solution. An optimum under relaxation factor is one that minimizes computer time and also prevents divergence. The determination of an optimum under relaxation factor, as in the choice of convergence control options, requires experience and trial and error. The under relaxation factor is activated by the use of the RELAX command in group 17 of the Q1 file.

The second convergence option, termination criteria for inner iterations, controls the number of iterations performed on a dependent variable for each sweep. A larger number of iterations per sweep will yield a more accurate value for that variable and thus result in fewer sweeps but the computing time per sweep is increased. A balance between the number of inner iterations per sweep and the number of sweeps is required. It would be a waste of computing time to iterate on a variable to a degree of accuracy exceeding the required accuracy of the output. The number of inner iterations is controled by the command LITER in group 16 of the Q1 file.

The incrementation of source terms is a method used to slowly apply the excitation to the flow system thereby reducing the jump required in solving the conservation equations. The total excitation to the system is obtained by applying the source, such as mass flow rate or temperature, in small increments. The magnitude of the excitation is increased after run of sweeps has converged based on the previous excitation magnitude. This procedure is in effect a transient to steady state flow condition solution.

For the first parametric study involving the effects of augmenter tube length on system behavior, a converged solution with a ten percent reduction in augmenter tube length was desired. Having little experience at this time with PHOENICS, the same under relaxation factors and number of inner iterations were used as in the original Hush House model Q1 file developed by Nicolaus. The variable FACT is used to define the magnitude of the FALSDT under relaxation factor. A value of FACT = 0.75 was applied to the dependent variables U1, V1, W1, KE, and EP. A value of 2.5 x FACT was used for the dependent variable H1. The variable LINRLX is used to define the linear under relaxation factor. A value of LINRLX = 0.3 was used for the variable P1. The default value of LITER equal to 20 iterations per sweep was used for all dependent variables. The DF09 file from the original Hush House converged solution was restarted. To avoid a jump or shock to the system the original augmenter tube length was initially reduced by 5 percent with 2500 sweeps required for a converged solution. The augmenter tube length was shortened an additional 5 percent of the original length with

3500 sweeps required for a converged solution. Each of the 32 runs, consisting of either 300 or 80 sweeps, exhibited monotonic convergence.

For the second parametric study involving the effects of turbulent viscosity on system behavior a trial and error procedure for obtaining convergence was required. The multiplying factor MF of equation (3.10) was set equal to 200. The DF09 file from the original Hush House model was used for a restart with the exceptions of the dependent variables KE and EP which were not required for the new temperature dependent turbulence model . Still having limited experience with PHOENICS, the same under relaxation factors and number of inner iterations were used as in the original Hush House model Q1 file. The above procedure resulted in divergence of the solution. The number of iterations, LITER, for the pressure variable P1 was increased from the default value of 20 to 40 because in the SIMPLE algorithim the pressure is solved for first from the continuity equation and then the velocity components are solved from the momentum equations which have a pressure gradient term. A more accurate value of pressure obtained by more iterations will yield more accurate velocity components without having to increase the number of iterations performed on them. The variable LINRLX was reduced from 0.3 to 0.1 for pressure variable P1. The under relaxation factor, FACT was reduced from 0.75 to 0.25 for the remaining variables U1, V1, W1, H1. These three changes resulted in an oscillation of residuals with an overall mean effect of neither increasing nor decreasing. It was evident that after nearly a thousand sweeps that the solution was not going to converge within an acceptable time frame. The next attempt at obtaining a converged solution involved incrementing the temperature source from the jet engine exhaust. The exhaust temp was set equal to ambient air at 295 ° K and the problem was started from scratch and not a restart from the original model. The mass flow rate was maintained at 38.49 kg s. The first few runs, consisting of 80 sweeps each, exhibited monotonic convergence. FACT was then increased from 0.25 to 1.0 to minimize computer CPU time. Monotonic convergence was present during the 1680 sweeps required for a final solution with engine exhaust temperature at 295 ° K. Engine exhaust temperature was increased to 500 ° K and a converged solution was obtained in 5280 sweeps. With the engine exhaust temperature incremented to 700 ° K, an additional 3100 sweeps were required for a converged solution. With the engine exhaust temperature set to 900 ° K, the residuals oscillated severly, yet the mean values were neither converging nor diverging over successive runs. FACT was incremently reduced to 0.1 and LINRLX remained at 0.1. After nearly 5000 sweeps, oscillation of the residuals continued with the same mean effect as exhibited by the residuals of the first few runs. This dilemma of non convergence non divergence is a prime example of not choosing the correct convergence control options. It should be fully understood that the solution of the flow field with engine exhaust temperature at 900 ° K is feasible but it requires a different approach than that used for the lower temperatures. Due to the shortage of time remaining for this turbulence study and the anticipated convergence problems at higher temperatures, it was decided to conduct the parametric study of turbulence using the converged solution with engine exhaust temperature at 700 ° K.

Three additional turbulent viscosity models were simulated with values of the multiply factor MF in equation (3.10) set to 1000, 20000, and 200,000. In addition, a solution for the original Hush House model (k- ε turbulence model) with the jet engine exhaust temperature set 700 ° K was simulated.

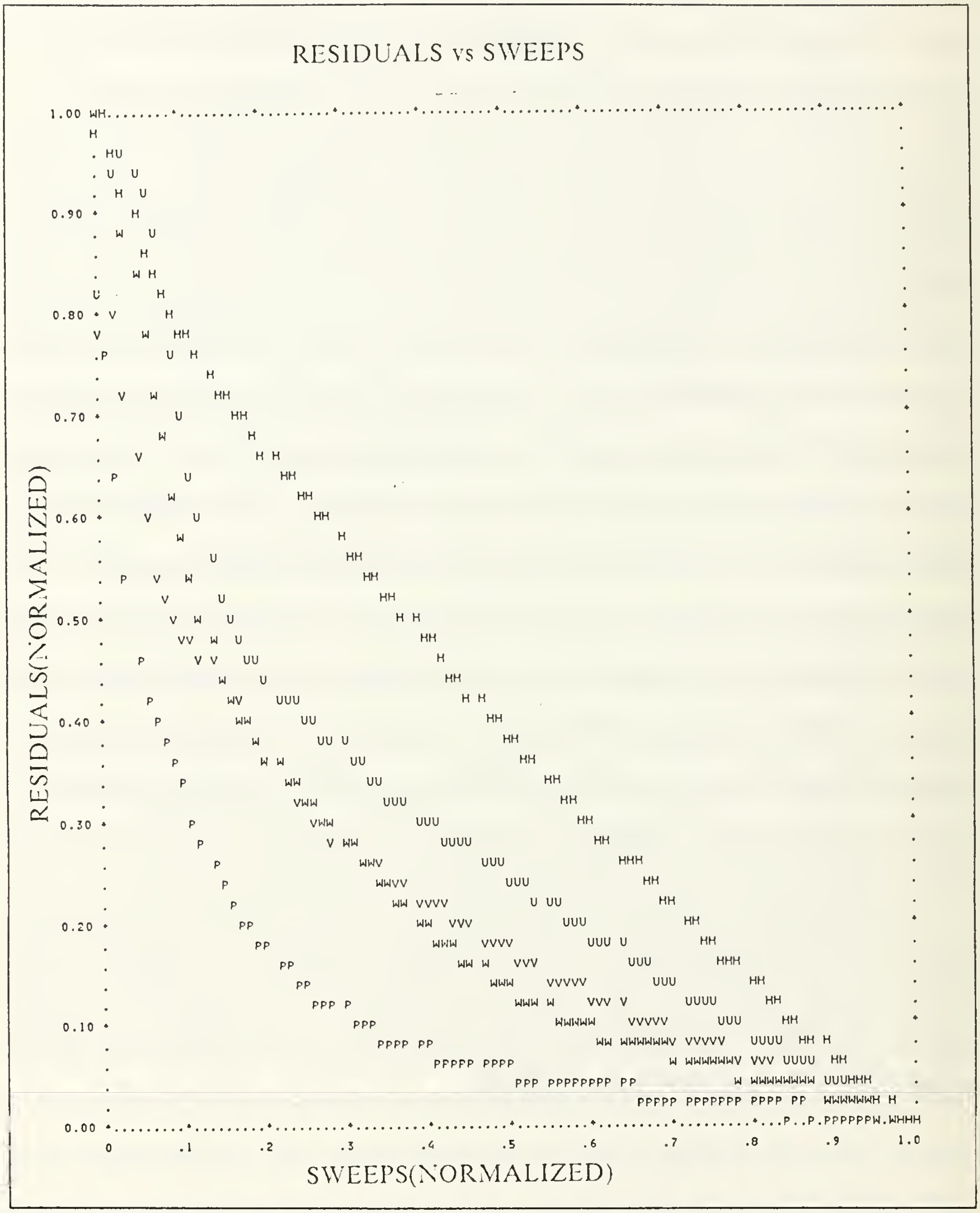

Figure 9. Sample Output Residuals vs Sweeps (Converging Solution)

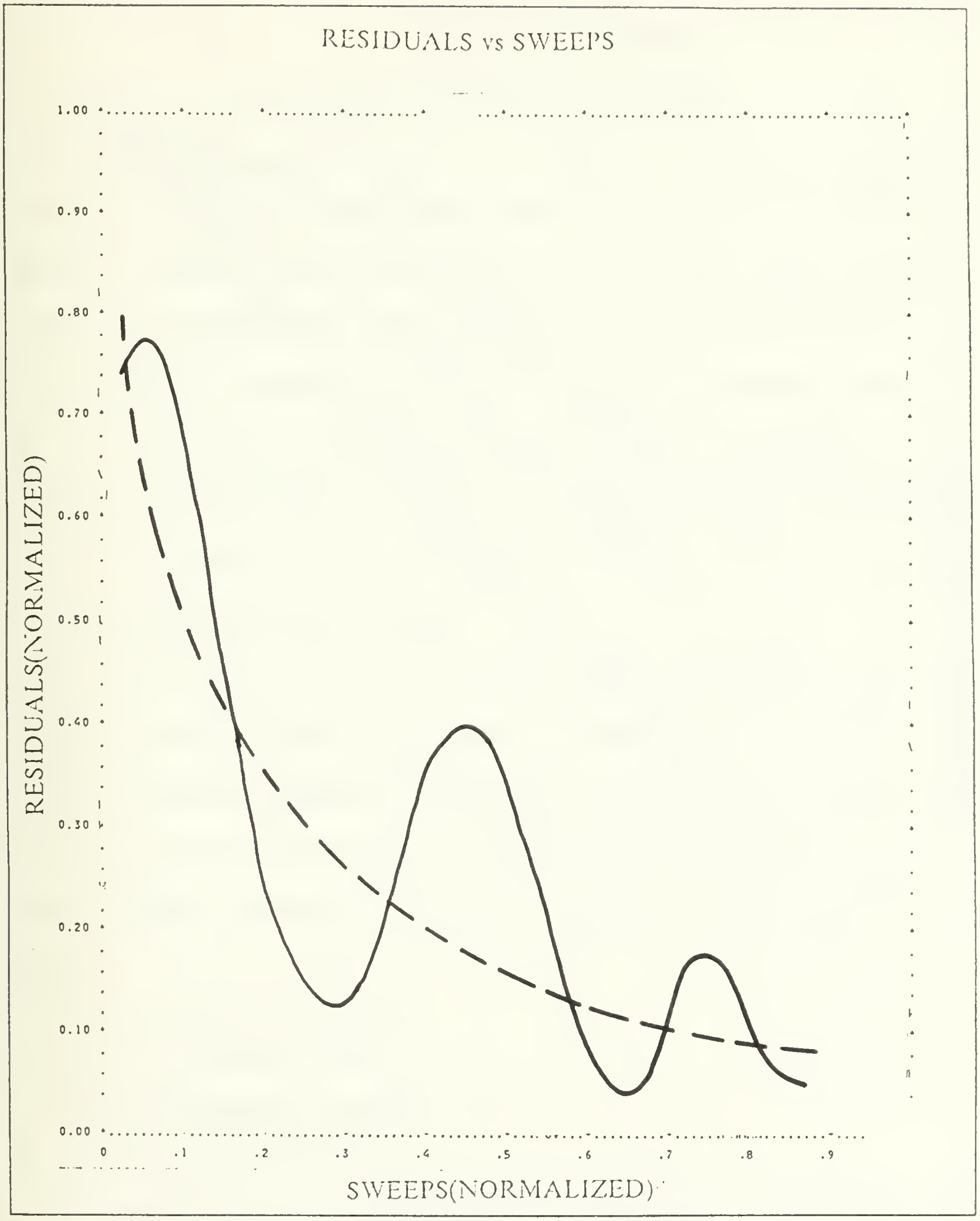

Figure 10. Sample Output Residuals vs Sweep (Converging Solution)

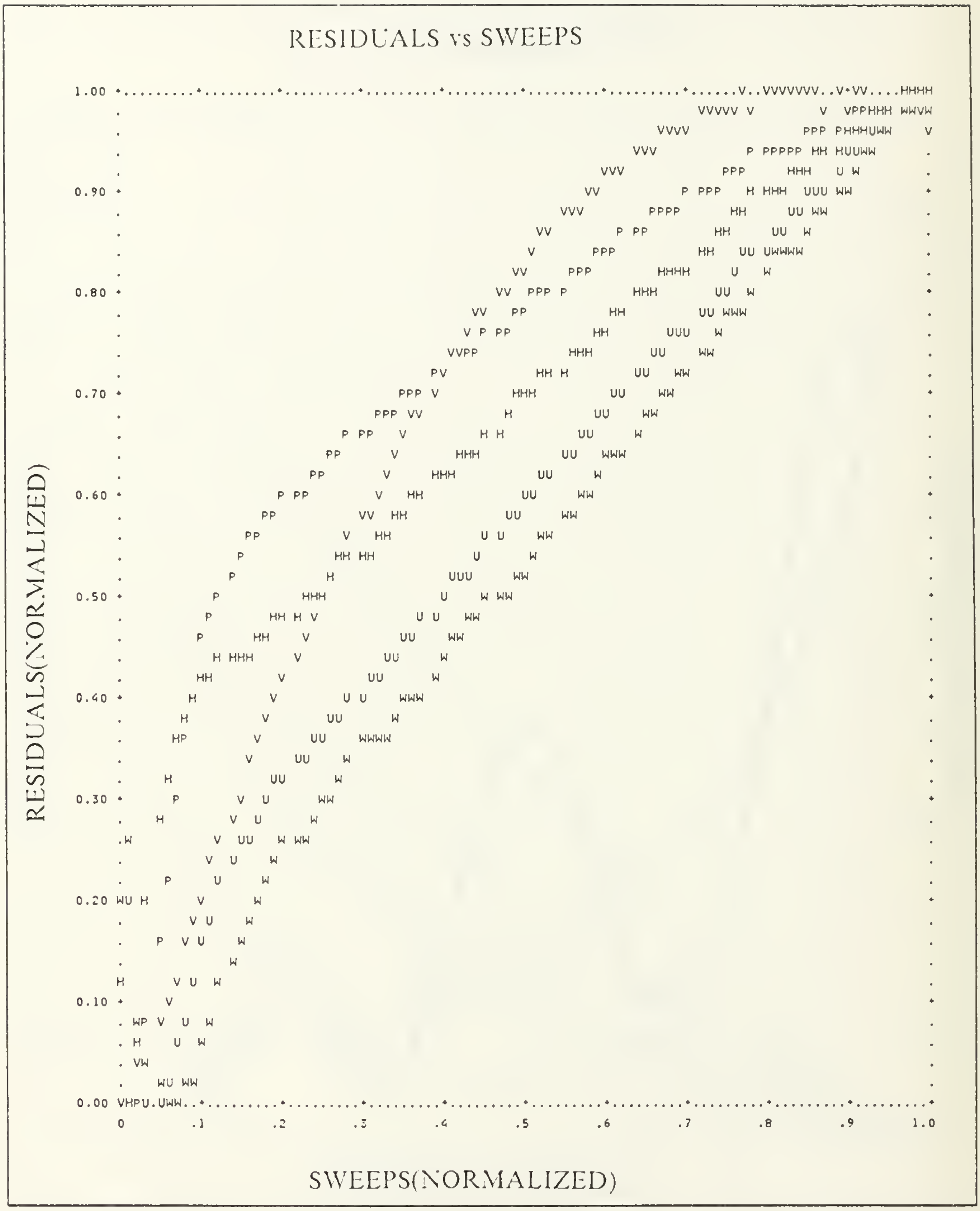

Figure 11. Sample Output Residuals vs Sweeps (Diverging Solution)

V. USING THE PHOENICS CODE

The efficient and successful utilization of PHOENICS requires a thorough understanding of the PHOENICS Code, the user manual, and the various computing facilities required to operate the PHOENICS Code. It is extremely difficult to obtain a thorough understanding of PHOENICS in a six month period. User manuals in general can not provide every bit of information required to fully operate and understand a system. This section is provided as an additional resource of information to help eliminate common problems encountered using PHOENICS. It is intended that this information will reduce the many setbacks that the beginning users of PHOENICS are sure to stumble on.

A. ALLOCATING MVS DATA SETS

The PHOENICS code is run as a batch job on the IBM 3033 main frame computer. The batch system at the NPS Computing Center is MVS (Multiple Virtual System). The MVS system introduces programs to the computer, initiates their execution, and schedules all resources and services required. MVS data sets must be allocated prior to running the Q1 file. For cartesian coordinate system grid, the following data sets are required:

1. MSS.S****.PHOENICS.DF09
2. MSS.S****.PHOENICS.DF10
3. MSS.S****.PHOENICS.LOAD
4. MSS.S****.PHOENICS.SRC

Where **** should be replaced with the users NPS computer ID number. MVS data sets are allocated by use of the CMS command MVSHELP. Select option 2 for allocation of new data sets. The computer will prompt for the required information. If the body fitted coordinate (BFC) grid system is used instead of the cartesian coordinate grid system, then two additional data sets are required:

1. MSS.S****.PHOENICS.DF12
2. MSS.S****.PHOENICS.DF16

Table 1 lists the data set parameters for the six required files.

Table 1. DATA SET PARAMETERS

DATA SET	RECFM	LRECL	BLKSI	DSORG
DF09	VBS	19004	19004	sequential
DF10	F	800	800	sequential
DF12	F	400	400	sequential
DF16	F	400	400	sequential
LOAD	U	N A	13030	partitioned
SRC	FB	80	80	partitioned

Another option of allocating MVS data sets and by far the easiest method is to rename a previous PHOENICS users data sets using the CMS command MVSHELP option 4 the rename option. All MVS data sets are accessible to anyone via the CMS commands MVSHELP and GETMVS. This procedure will eliminate the problem of allocating space for empty data sets for PHOENICS.DF12 and PHOENICS.LOAD which results in error messages when running the Q1 file for the first time.

A few words of caution are needed at this point concerning MVS data sets. If the DF09 file is transferred from another user, the restart option in group 24 of the Q1 file should not be used (i.e.,RESTRT should be deactivated) the first time the Q1 file is run unless the data stored on the DF09 file is to be used as input data. After the first run invoke the restart option. DF09 is the file that the grid geometry and PHOENICS generated output is stored on. Each time the problem is run the output from the previous run is read from the DF09 file as the input data for the present run. The output for any run writes over the previous output on the DF09 file. file. This procedure allows sequential runs to be performed with the latest output being submitted as the present input data for a restart. In order to save good output files and prevent them from being written over, the DF09 file must be copied onto a different backup MVS data set. The program COPYTAPE listed in Appendix B provides the means of copying any MVS data set to another MVS data set. The new MVS Data File must be allocated prior to copying and have the same MVS parameters as the one that is being copied. The name of the new file is arbitrary but the recommended name form is:

MSS.S****.PHOENICS.BACKUP

Where **** is the users computer ID number and BACKUP is the new file name (or any other file name). The function of COPYTAPE is to copy the SYSUT1 data set to the SYSUT2 data set. COPYTAPE can be used to copy the PHOENICS output file onto the backup file or copy the backup file onto the DF09 file which would be used as the input data for the next run of the Q1 file. It is strongly recommended to copy the DF09 file onto a backup file on regular intervals such as on a daily or bi-weekly basis. It is possible that the DF09 file could contain bad data as a result of a change in the Q1 file or the submission of a different Q1 file having the same computer ID numbers. If this dilemma occurs and the backup files are utilized, only a loss of several days of computing would be lost, vice weeks or months if backup files were not utilized.

B. IMPLEMENTING GROUND

GROUND is the program for interaction with the EARTH solution program. The implementation of GROUND requires five steps:

1. Insert relevent equations into the file GROUND FORTRAN
2. Submit COPYGRD
3. Submit COMPGRD
4. Compact LOAD and SRC MVS data sets

5. Submit LINKEAR JCL

Group 9 of the GROUND FORTRAN file is shown in Appendix C. Section 5 contains the coding required to evaluate ENUT (equation (3.10)) used in the Hush House turbulence study. The programs COPYGRD, COMPGRD, AND LINKEAR are included in Appendix D for reference. Compacting the LOAD and SRC files requires the sequential submission of three programs for each file. For the LOAD file the following programs listed in Appendix E are required:

PHOENX01 LOADLIB
PHOENX02 LOADLIB
PHOENX03 LOADLIB

For the SRC file the following programs listed in Appendix E are required:

PHOENX01 SOURCELB
PHOENX02 SOURCELB
PHOENX03 SOURCELB

When the LOAD data set has been copied from a previous user it will contain the equations placed in the GROUND FORTRAN file by the previous user. If the equations in GROUND FORTRAN are not required, ensure that the command USEGRD = F is inserted in group 19 of the Q1 file.

C. DATA TRANSFER FROM MVS TO VAX

Although the PHOENICS Code is available on the NPS computer center IBM Mainframe, the graphics program PHOTON is only available on the VAX system. Therefore in order to have data transfer of the DF09 file from MVS to the VAX 2000 system a data transfer operation is required. Presently there are two methods available for data transfer at NPS. The first method involves copying the DF09 data set to a CMS file and then transferring the CMS file via a modem from the mainframe to the VAX system. The computer hardware and software for the procedure has not been fully debugged. More often than not, the transfer of data is interrupted and data transfer is seldom successful. Until the system has been debugged, it is strongly recommended to avoid this procedure as it is simply inefficient and undependable.

The second method available is to transfer the DF09 MVS data set to a 9 track tape and then transfer from the tape to a VAX cartridge. Prior to transferring the DF09 data file to the 9 track tape, the unformatted DF09 file must be formatted so that the file can be read by PHOTON. The program FORM09 in Appendix F transforms the original unformatted DF09 file into a new formatted DF09C file. The new DF09C file must be allocated using MVSHELP prior to submitting FORM09. The proper setting of the parameters for DF09 are crucial. The data set organization, record format, logical record length, and blocksize must be set as listed below. The number of primary and secondary storage tracks allocated to the DF09C file may vary depending on the size of the DF09 file.

Data set organization = Sequential (PS)
Record Format = Fixed Block (FB)
Logical record length = 80
Blocksize = 800
Primary Allocation = 250 (TRK)
Secondary = 16 (TRK)

A nine track tape may be checked out from the NPS computer center. A non labeled tape with a density of either 1600 or 6250 bits per inch (bpi) is required. If several files are to be transfered to tape, the 6250 density tape is recommended due to its larger capacity. The program SEQ5, a utility program available through the MVSHELP command , copies the formatted DF09C file to the 9 track tape. The tape to VAX cartridge transfer equipment is located in the lab of the NPS Meteorology Department (Donna Burych is the point of contact for computer access authorization). The following VAX commands are required for data transfer from tape to VAX cartridge:

```
Mount For Record = 80 Blcoksize = 800 MSAO:
Mount Record = 80 Blocksize = 800 MUAO:
Copy MSAO:  MUAO: FN.FT
Dismount MSAO:
Dismount MUAO:
```

During the data transfer ignore the "incompatible attributes" message. It has no effect on the transfer operation. When using the cartesian coordinate grid system (which does not reqiure the use of MVS DF12 data set), the DF09 file on the VAX cartridge does not require any editing to be compatible with the Phoenics version 1.4 on the VAX.

In running the PHOENICS Code it is inevitable that computing errors will occur. Listed below are some of the common error codes encountered along with the corrective action required:

Abend code 322 - allocated CPU time has been exceeded. The number of sweeps per run must be reduced. In the Hush House model a maximum of 90 sweeps for a 15 minute class G job and 360 sweeps for a 60 minute class J job were possible. The time per sweep is dependent on the number of equations being solved and the number of iterations (LITER) for each variable.

Abend Code SE37 - The LOAD and SRC files require compacting. The compacting procedure is discussed in section B of this chapter.

VI. COMPUTER MODEL RESULTS

The parametric study of the aerothermodynamics of the NAS Jacksonville, Florida Hush House consisted of two independent studies. The first study investigated the effects of a 10% reduction of the augmenter tube length on system behavior. The second study investigated the effects of turbulence model on system behavior. For ease in differentiating the different Hush House models, the following terms are defined and will be referred in the discussion of results:

Model 1 - Original Hush House Model utilizing the k - ε turbulence model (TJET = 1944 ° K)

Model 2 - Hush House Model with 10% reduced augmenter tube length utilizing the k - ε turbulence model (TJET = 1944 ° K)

Model 3 - Hush House Model utilizing equation (3.10) for turbulent viscosity (MF = 200000, TJET = 700 K)

Model 4 - Hush House Model utilizing equation (3.10) for turbulent viscosity (MF = 20000, TJET = 700 K)

Model 5 - Hush House Model utilizing equation (3.10) for turbulent viscosity (MF = 1000, TJET - 700 K)

Model 6 - Hush House Model utilizing equation (3.10) for turbulent viscosity (MF = 200, TJET = 700 K)

Model 7 - Original Hush House Model utilizing k - ε turbulence model (TJET - 700 K)

The tabulated numerical results generated by PHOENICS for each of the 7 models are comprised of nearly 10000 lines of data. For ease of comparing results, output data is presented in graphical form for pressure, temperature, and velocity profiles and contours.

A. AUGMENTER TUBE LENGTH STUDY

This study compares the results of model 1 (the original model) and model 2 (the original model with a shortened augmenter tube). The pressure, temperature, and velocity profiles from IZ = 1-40 at IX = 1 and IY = 4 for model 1 and model 2 are shown in Figure 12 on page 43, Figure 13 on page 44 and Figure 14 on page 45. The pressure profile shows identical values of pressure for both models from Z = 0 to Z = 27.4 meters. The pressure in model 2 is approximately 40 pascals higher than in model 1 from Z = 27.4 to Z = 45.6 meters. The latter distance represents the 10% shorter augmenter tube length. The remaining section of the model 2 profile is identical to the model 1 profile except that it is shifted to the left a distance of 2.1 meters, which is equal to the reduction in augmenter tube length. The distance axis is normalized by using the cell numbers in the Z direction vice actual distance in the Z direction as shown in Figure 15 on page 46. The normalized profile shows more clearly that there is little if any change in pressure magnitudes between the two models. Similarly for the normalized temperature and velocity profiles shown in Figure 16 on page 47 and Figure 17 on page 48 there is no significant changes in temperature and velocity magnitudes between the two models. Velocity vector plots, temperature contours, and pressure contours of model 1 and model 2 are shown in Figure 18 on page 49 through Figure 29 on page 60. Figure 18 on page 49 and Figure 19 on page 50 show the velocity vector plots in the test bay at engine level (IY = 4) are identical for model 1 and model 2. Figure 20 on page 51 and Figure 21 on page 52 show the vector velocity plots at the exhaust of the augmenter tube are identical for model 1 and model 2. Figure 22 on page 53 and Figure 23 on page 54 show the temperature contours in the entrance of the augmenter tube are identical for model 1 and model 2. Figure 24 on page 55 and Figure 25 on page 56 show the temperature contours at the exhaust of the augmenter tube are identical for model 1 and model 2. Figure 26 on page 57 and Figure 27 on page 58 show the pressure contours at the entrance of the augmenter tube are identical for model 1 and model 2. Figure 28 on page 59 and Figure 29 on page 60 show the pressure contours at the exhaust of the augmenter tube are identical for model 1 and model 2. These figures provide verification that the shorter augmenter tube has little effect on the aerothermodynamics of the flow field. In addition to comparing profiles and contours of model 1 and model 2, the augmentation ratios of each model are compared. The augmentation ratio is defined as follows:

$$A.R. = \frac{\dot{M}_{IN} - \dot{M}_{ENG}}{\dot{M}_{ENG}}$$

where:

M_{IN} = inlet mass flow rate
M_{ENG} = engine mass flow rate

The inlet mass flow rate is the sum of the mass flow rates through the five air inlet doors in the test bay. The engine mass flow rate of 38.49 $\frac{kg}{sec}$ is the same in both models. The augmentation ratio is a measure of the efficiency of the Hush House in regards to the magnitude of the mass flow rate of secondary cooling air that can be drawn into the Hush House by the "entrainment effect" of the jet engine exhaust. The higher the augmentation ratio the higher the efficiency of the Hush House design. The augmentation ratio for model 1 is 10.66 and for model 2 is 10.87. This amounts to an increase of 2% of the augmentation ratio for model 2 compared to model 1.

The 10% shorter augmenter tube is slightly more efficient than the original model. Although the pressure, temperature, and velocity of the exhaust gas as it enters the atmosphere is not effected by the shorter tube, the noise level (not analysed in this thesis) is expected to be higher. Recall that the augmenter tube is lined with acoustic absorption material. Reducing the augmenter tube reduces the surface area of the absorption material thereby reducing the amount of acoustic energy absorbed.

B. TURBULENCE STUDY

The effects of turbulence model on system aerothermal behavior are presented in pressure, temperature and velocity profiles and contours. The magnitudes of the turbulent viscosity, resulting from equation (3.10) , in the arbitrarily selected cell defined by IX = 1, IY = 4, and IZ = 20 for model 3, model 4, model 5, model 6, and model 7 are as follows:

model 3	MF = 200,000	$\nu_T \approx 6.4 \frac{Ns}{m^2}$
model 4	MF = 20,000	$\nu_T \approx 1.1 \frac{Ns}{m^2}$
model 5	MF = 1000	$\nu_T \approx 0.06 \frac{Ns}{m^2}$
model 6	MF = 200	$\nu_T \approx 0.01 \frac{Ns}{m^2}$
model 7	k- ε model	$\nu_T \approx 4.4 \frac{Ns}{m^2}$

It should be stressed that these values of ν_T are representative values of turbulent viscosity in one cell only. Values of ν_T are different in each of the cells of the model. The results from model 5 and model 6 are essentially the same and are therefore presented as a single model referred to as model 5&6. Model 7 (k- ε model) is included for the purpose of providing a relative reference point to gage the effects of the temperature dependent turbulence models. The pressure profiles for model 3, model 4, model 5&6, and model 7 are shown in Figure 33 on page 64. In the test bay area prior to the engine inlet (Z distance = 0 - 17.6 meters) the pressure profiles for each model are approximately constant. The noticable trend is that as the turbulent viscosity is increased from $\nu_T \approx 0.01$ to $\nu_T \approx 6.4$ the constant pressure profile for each model decreases by roughly 20 pascal. The trend continues for the large pressure depression just prior to the engine inlet (Z distance = 18.6 meters). After the engine exhaust (Z distance = 22.3 meters), little correlation between the pressure profiles and the magnitude of turbulent viscosity is observable. For low magnitudes of turbulent viscosity ($\nu_T \approx 0.06$ and $\nu_T \approx 1.1$) the pressure profile through the augmenter tube shows little variation. For higher magnitudes of turbulent viscosity ($\nu_T \approx 4.4$ and $\nu_T \approx 6.4$) the pressure profile through the augmenter tube varies from a nagative pressure to a positive pressure.

The temperature profiles for model 3, model 4, model 5&6, and model 7 are shown in Figure 30 on page 61. The temperature profiles of the four models are identical in the test bay (295 ° K), through the engine (250 ° K) to the engine outlet (700 ° K). It is clearly shown that as the magnitude of turbulent viscosity increases, the temperature decrease through the augmenter tube increases as a result of the increased mixing effect.

The velocity profiles for model 3, model 4, and model 5&6, and model 7 are shown in Figure 34 on page 65. The velocity profiles are similar to the temperature profiles in that the velocity decrease through the augmenter tube is increases as the magnitude of the turbulent viscosity increases.

Velocity vector plots in the test bay for model 3, model 4, and model 5&6 are shown in Figure 35 on page 66, Figure 36 on page 67, and Figure 37 on page 68. The velocity vector plot for model 7 is not included in the figures becuase of its similarity with the vector plot of model 4. The velocity vectors in model 7 have the same direction but a magnitude 1.5 times greater than the velocity vector plots in model 4.

The vector plot for model 3 shows a smooth flow of air to the engine and augmenter tube. The counterflows first observable in Figure 34 (model 4) become more pronounced in Figure 35 (model 5&6). It appears that in the test bay a higher magnitude of turbulent viscosity results in a more distortion free flow path to the engine and augmenter tube. Velocity vector plots at the augmenter tube exhaust for model 3 and model 4 are shown in Figure 31 on page 62 and Figure 32 on page 63. The velocity vector plots for model 5&6 and model 7 are not shown. Model 5&6 is identical to model 4 both in magnitude and direction. The velocity vectors in model 7 are identical in direction to model 4 but have a magnitude 1.5 times greater. The gas flow in model 3 exits to the atmosphere at a velocity of 30 $\frac{m}{s}$ and is uniformly distributed across the exhaust opening. The gas flow in model 4 exits at the far end of the exhaust opening at a velocity of 50 $\frac{m}{s}$. In addition, a counterclockwise vortex is present over the exhaust opening. As in the test bay, a higher magnitude of turbulent viscosity results in a more distortion free flow field.

The temperature contours in the area of the jet engine exhaust for model 3, model 4, model 5&6, and model 7 are shown in Figure 38 on page 69 through Figure 41 on page 72. Temperature contours at the augmenter tube exhaust for model 3, model 4, model 5&6, and model 7 are shown in Figure 42 on page 73 through Figure 45 on page 76. The temperature contours for model 3 ($\nu_T \approx 6.4$) shows the largest temperature decrease through the augmenter tube ($\Delta T = 382\ ^\circ K$). The temperature decrease through the augmenter tube for model 7 ($N_T \approx 4.4$) is $\Delta T = 341\ ^\circ K$, for model 4 ($\nu_T \approx 1.1$) is $\Delta T = 233\ ^\circ K$, and for model 5&6 ($\nu_T \approx 0.06$) is $\Delta T = 173\ ^\circ K$. The latter eight figures show that the temperature decrease through the augmenter tube increases as the magnitude of turbulent viscosity increases.

The pressure contours in the area of the jet engine exhaust for model 3, model 4, model 5&6 and model 7 are shown in Figure 46 on page 77 through Figure 49 on page 80. The pressure contours at the augmenter tube exhaust for model 3, model 4, model 5&6, and model 7 are shown in Figure 50 on page 81 through Figure 53 on page 84. The pressure contours from model 3 and model 7 are similar in that the pressure fields change from negative pressures in the augmenter tube entrance to a positive pressure at the augmenter tube exhaust. The pressure contours for model 4 and model 5&6 are similar in that the pressure fields are negative from the augmenter tube entrance to the exhaust stack. It appears that there is a crossover point of the magnitude of the turbulent viscosity in regards to distribution of the pressure field. For large magnitudes of ν_T (4.4 - 6.4 $\frac{Ns}{m^2}$) the pressure changes from negative to positive values. For small magnitudes of ν_T (0.01 - 1.1 $\frac{Ns}{m^2}$) the pressure field is always negative.

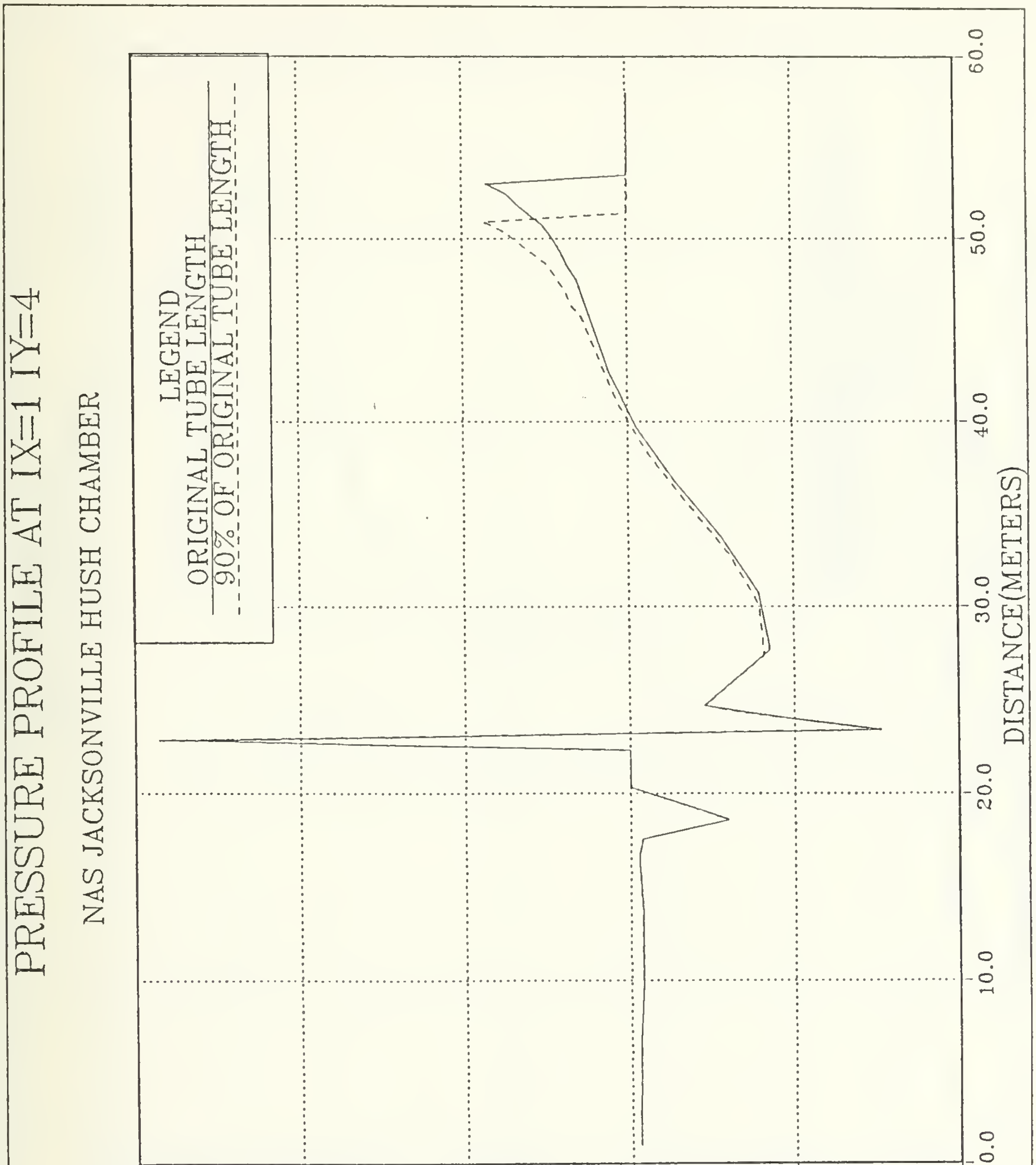

Figure 12. Augmenter Tube Length Study Pressure Profile

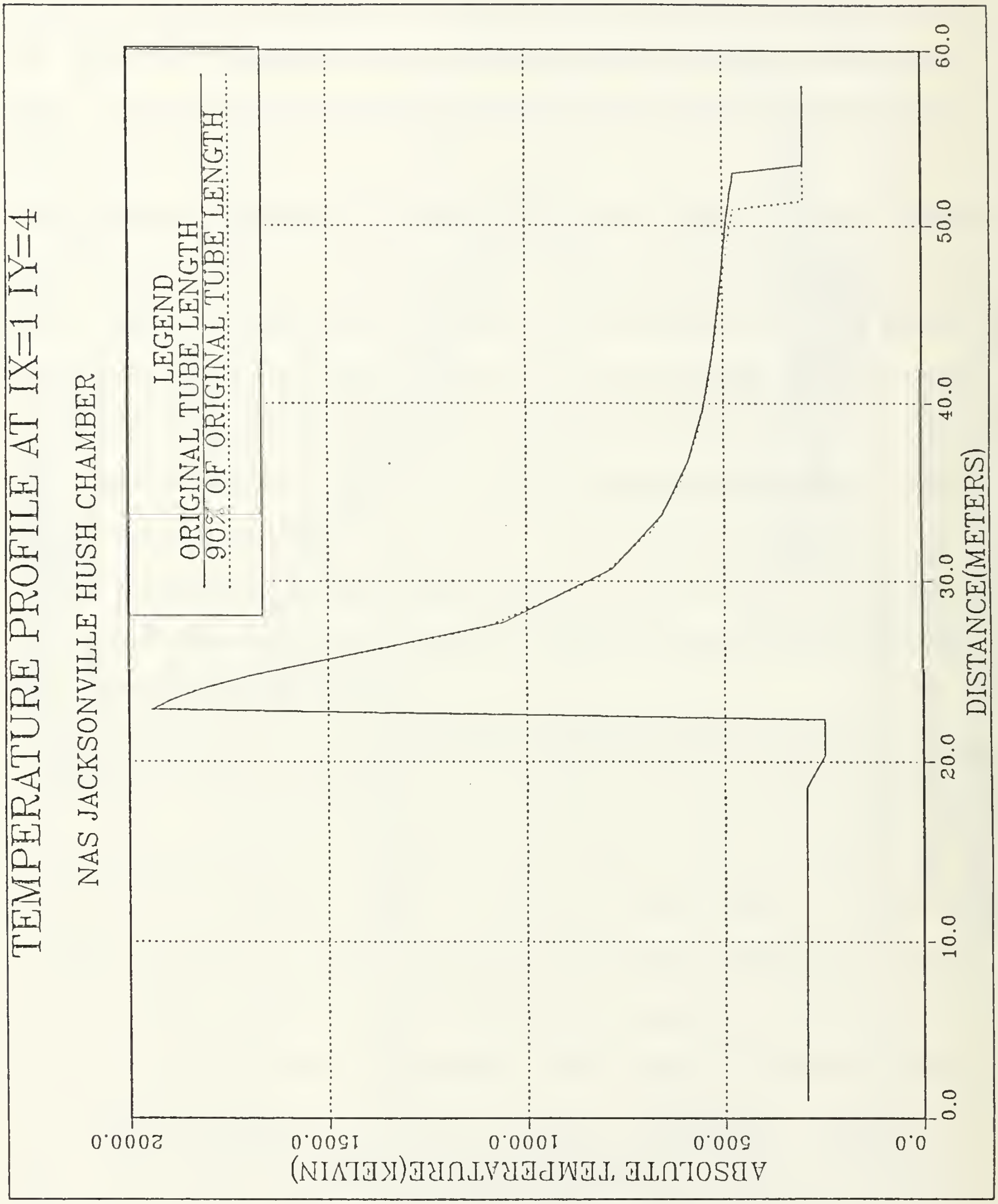

Figure 13. Augmenter Tube Study Temperature Profile

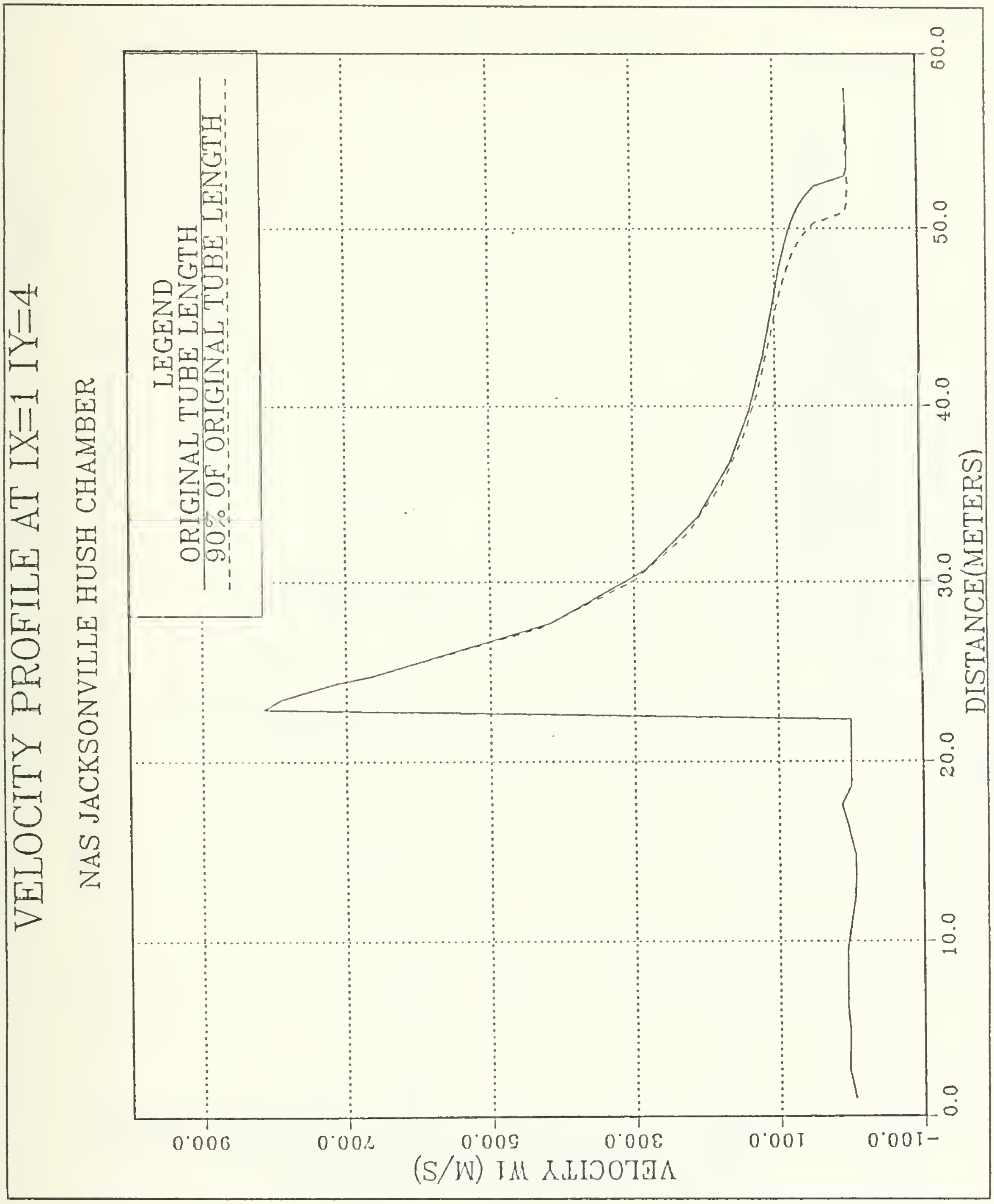

Figure 14. Augmenter Tube Length Study Velocity Profile

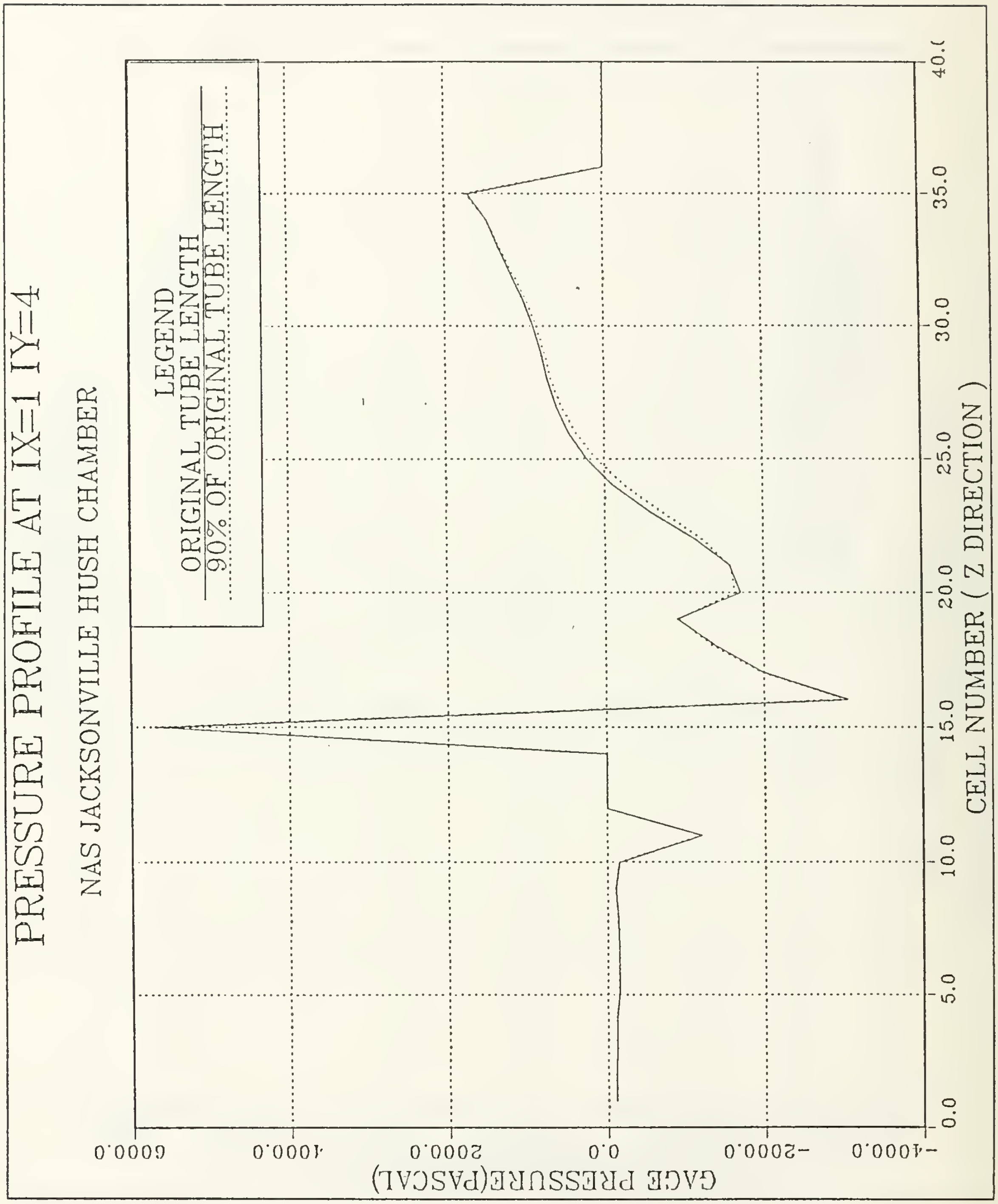

Figure 15. Augmenter Tube Study Pressure Profile (normalized)

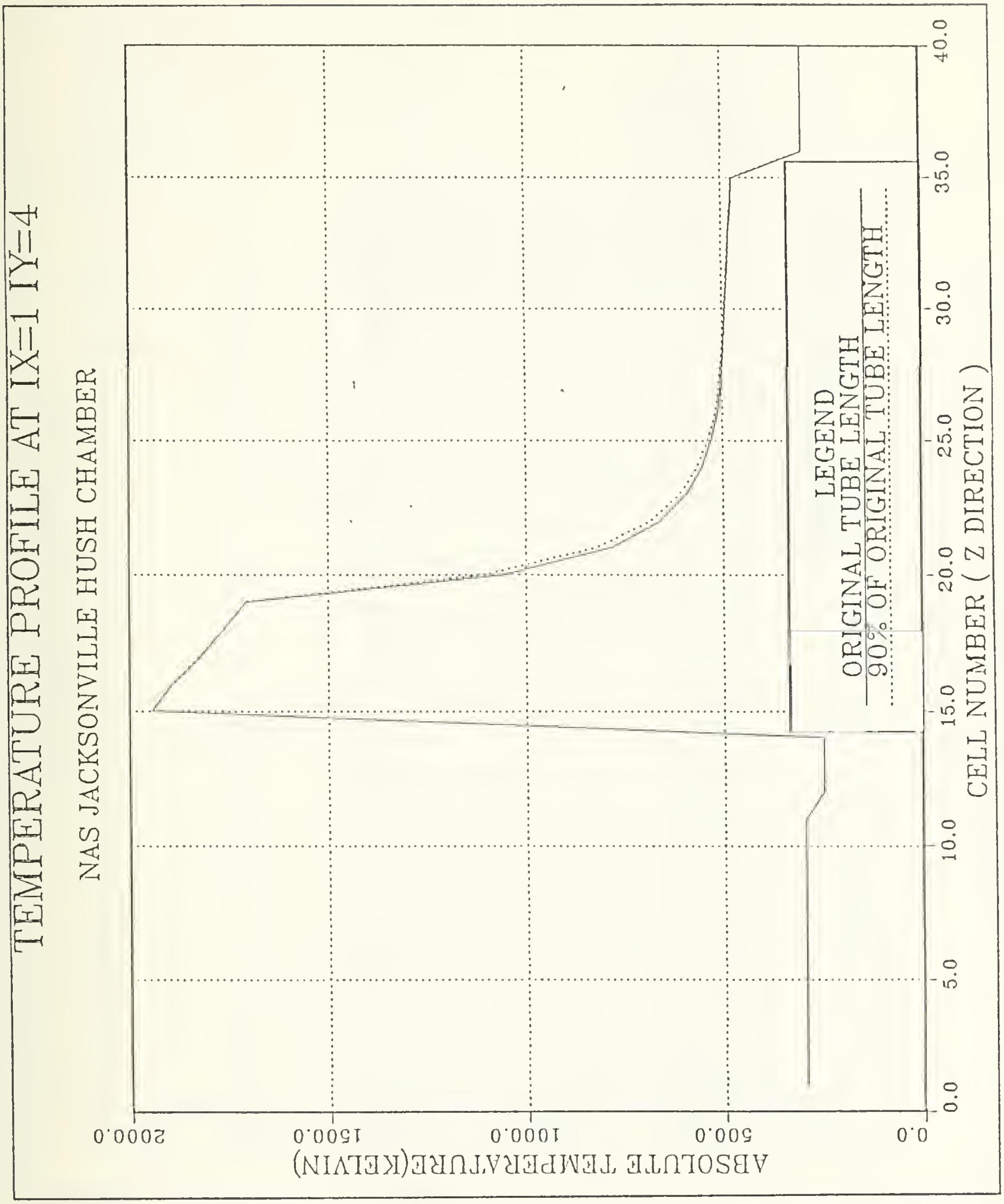

Figure 16. Augmenter Tube Study Temperature Profile (normalized)

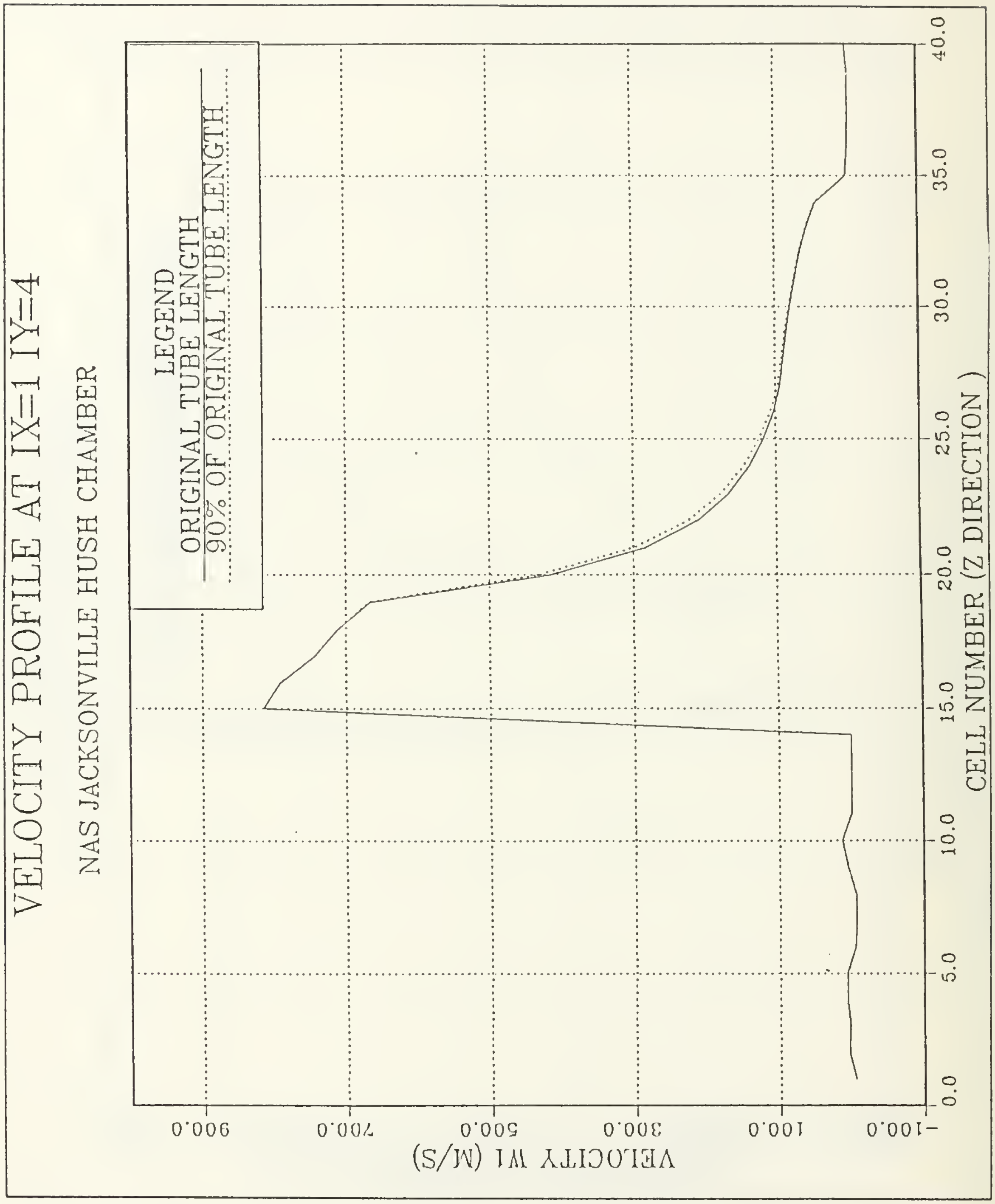

Figure 17. Augmenter Tube Study Velocity Profile (normalized)

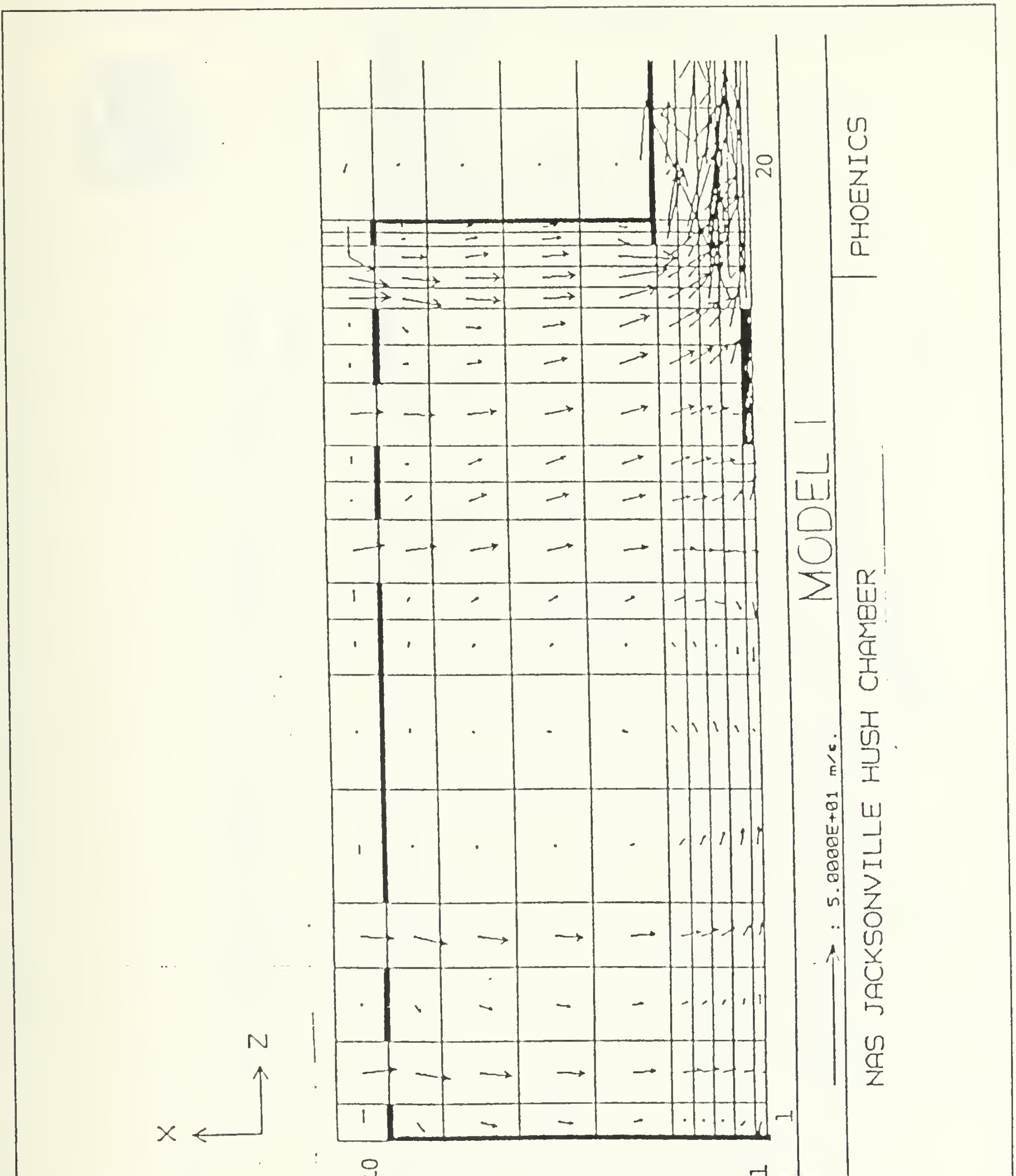

Figure 18. Velocity Vector Plot for Model 1 (test bay)

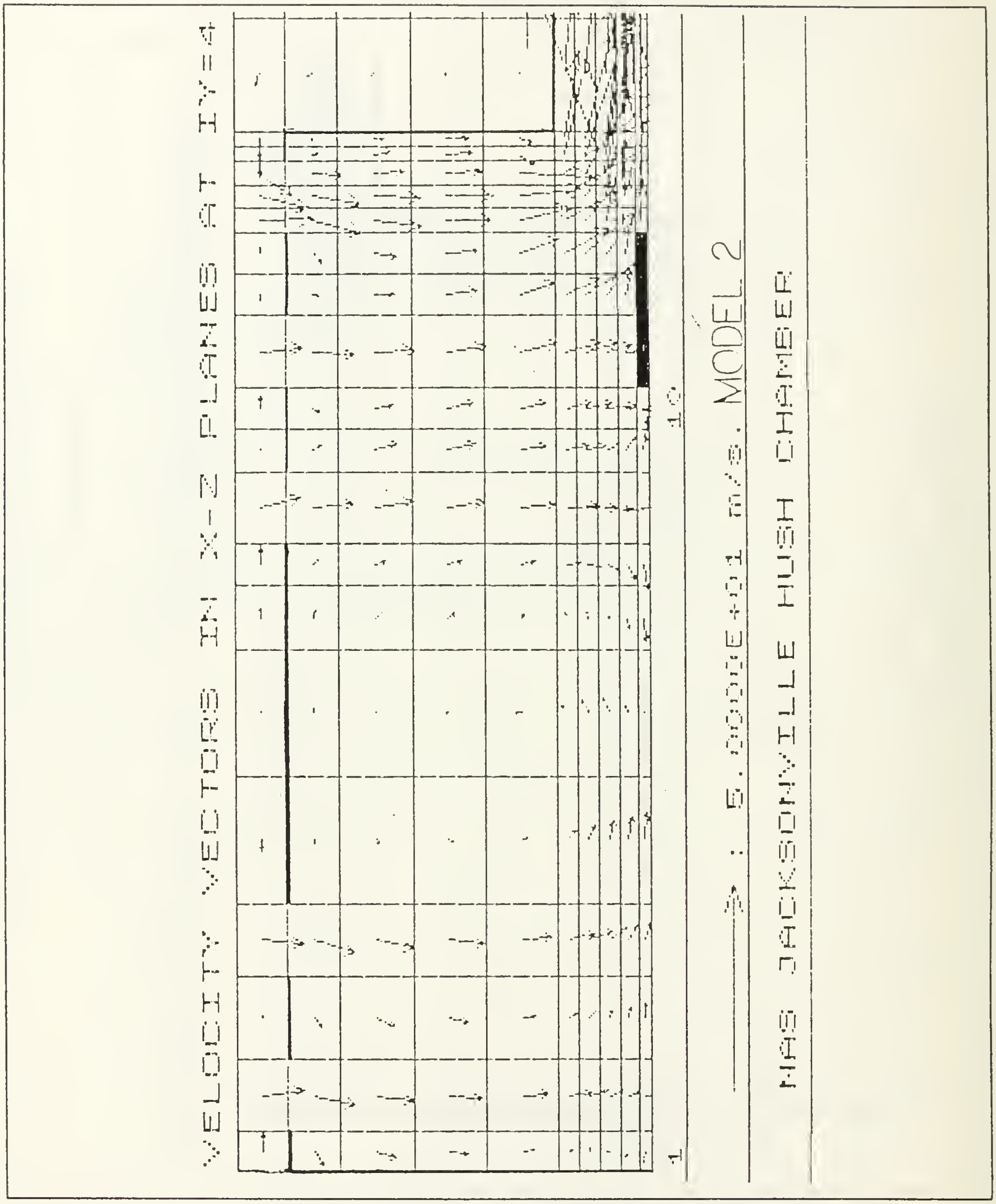

Figure 19. Velocity Vector Plots for model 2 (test bay)

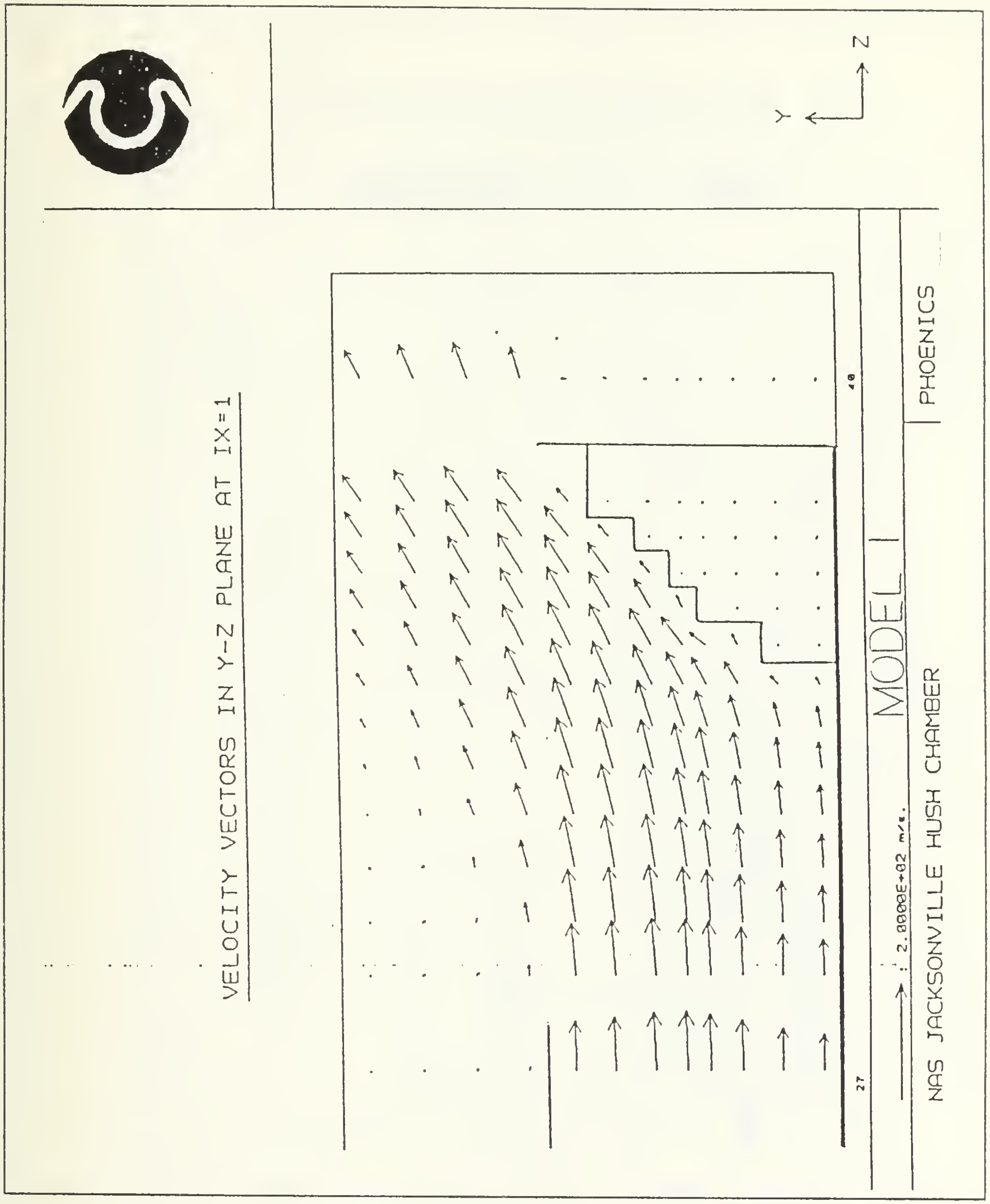

Figure 20. Velocity Vector Plot for Model 1 (exhaust)

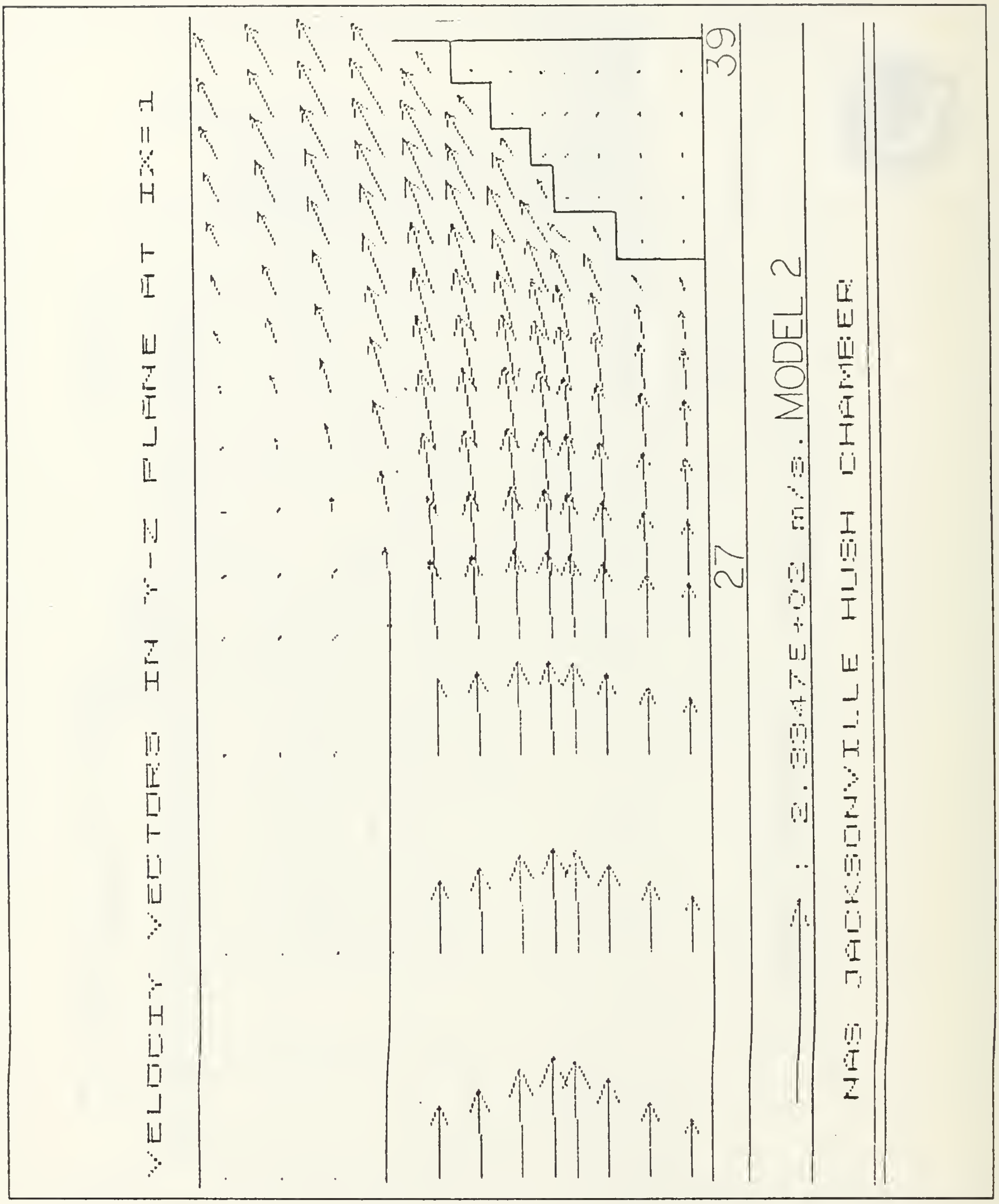

Figure 21. Velocity Vector Plot for Model 2 (exhaust)

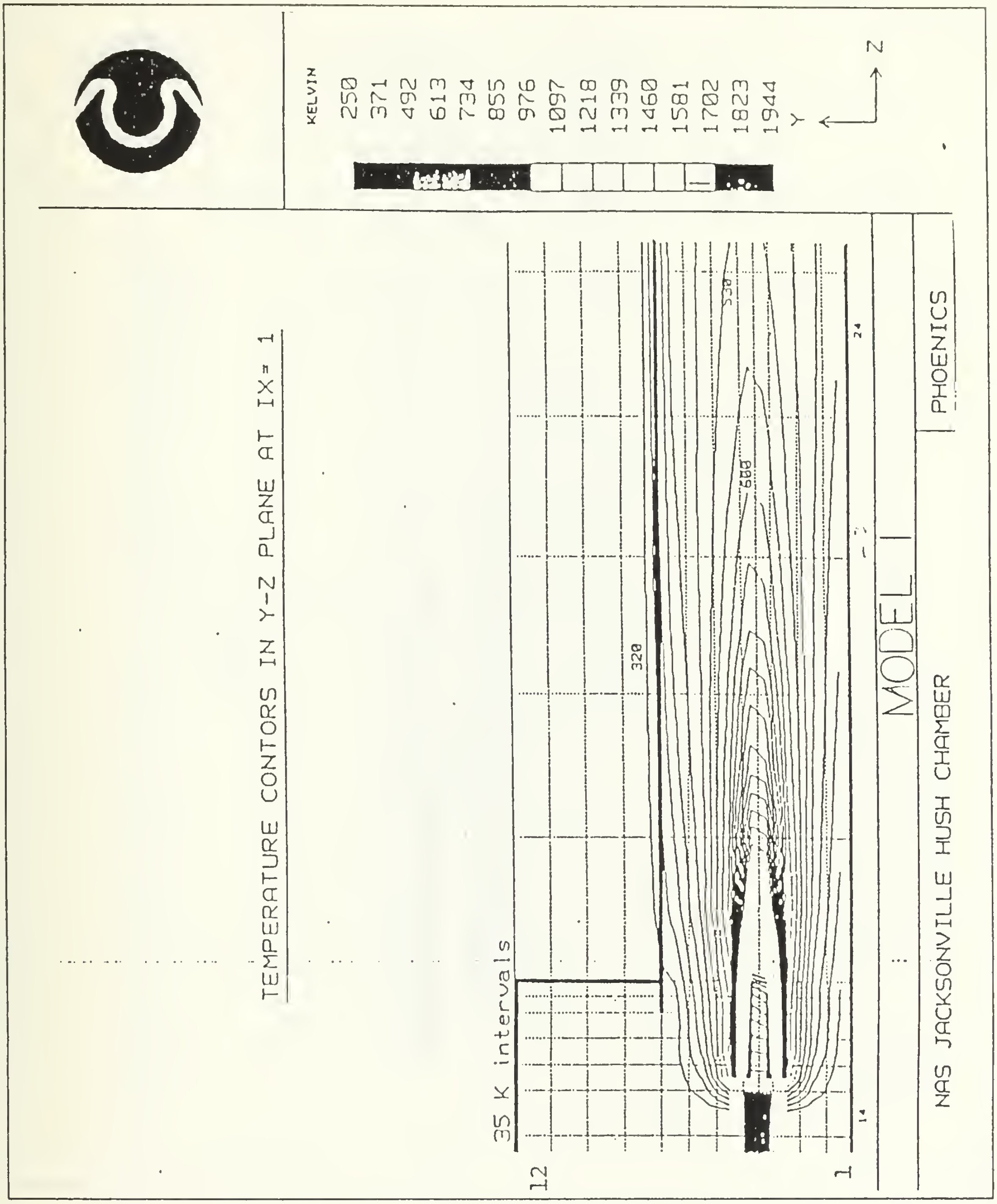

Figure 22. Temperature Contour for Model 1 (augmenter tube)

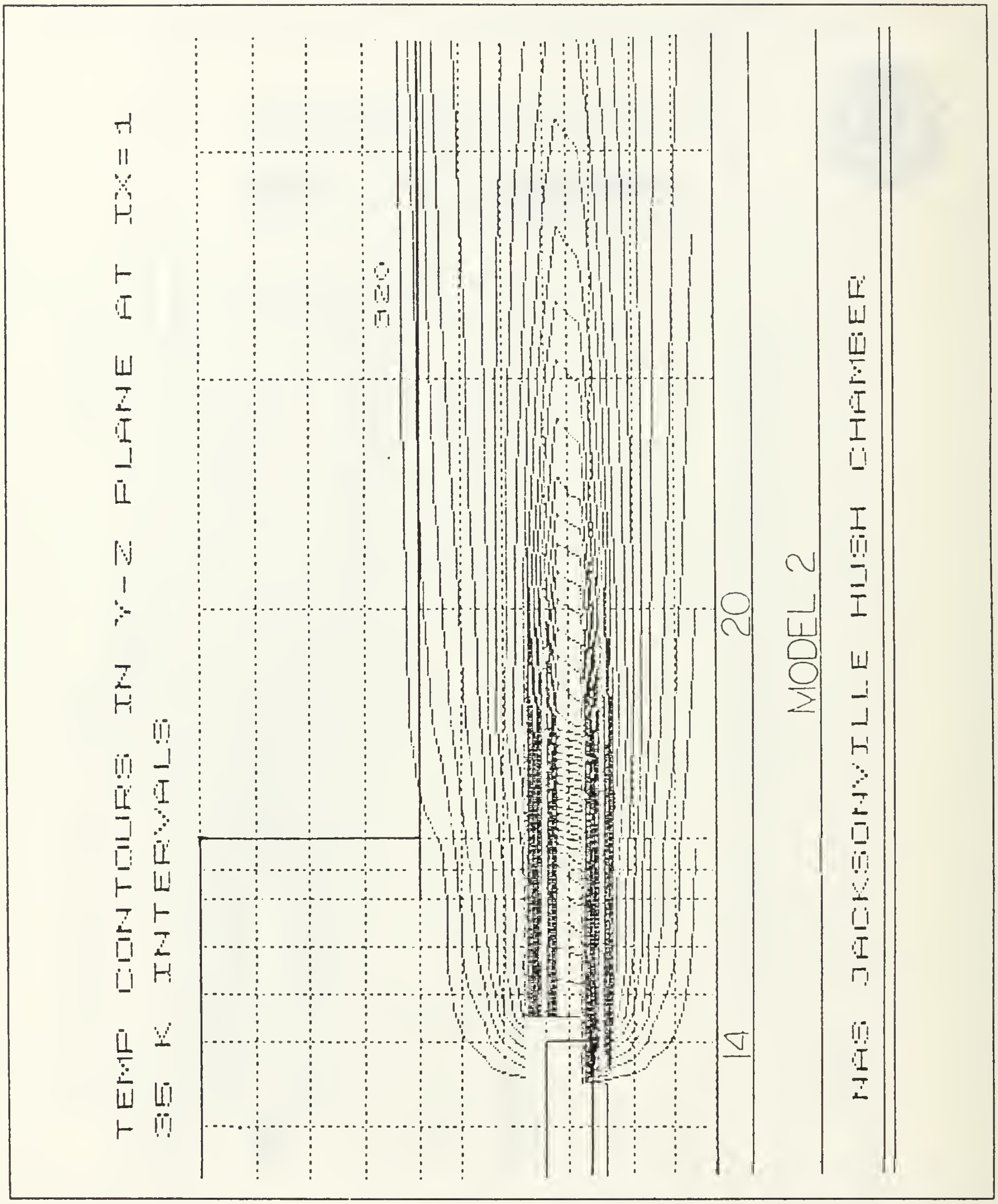

Figure 23. Temperature Contour for Model 2 (augmenter tube)

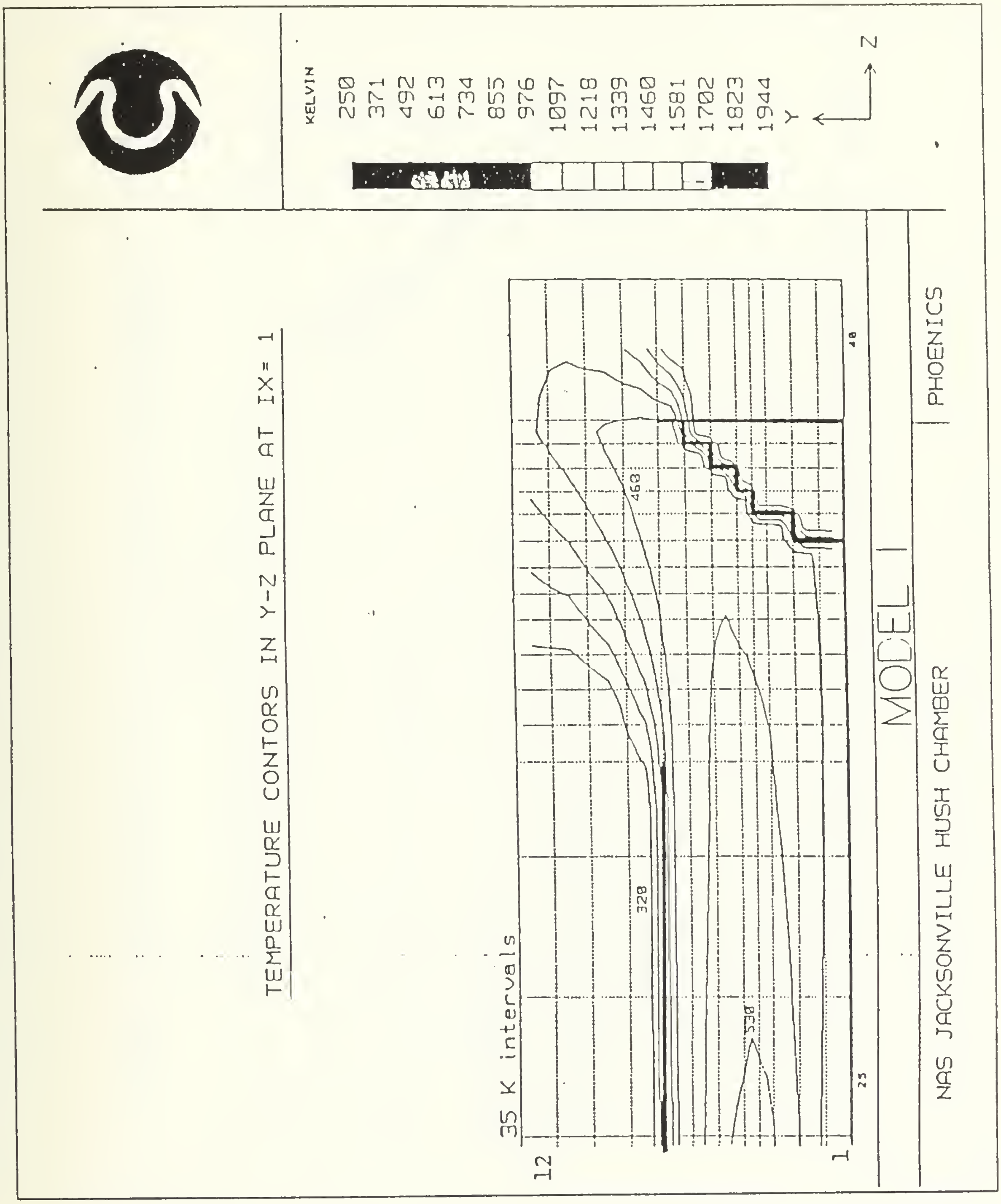

Figure 24. Temperature Contour for Model 1 (exhaust)

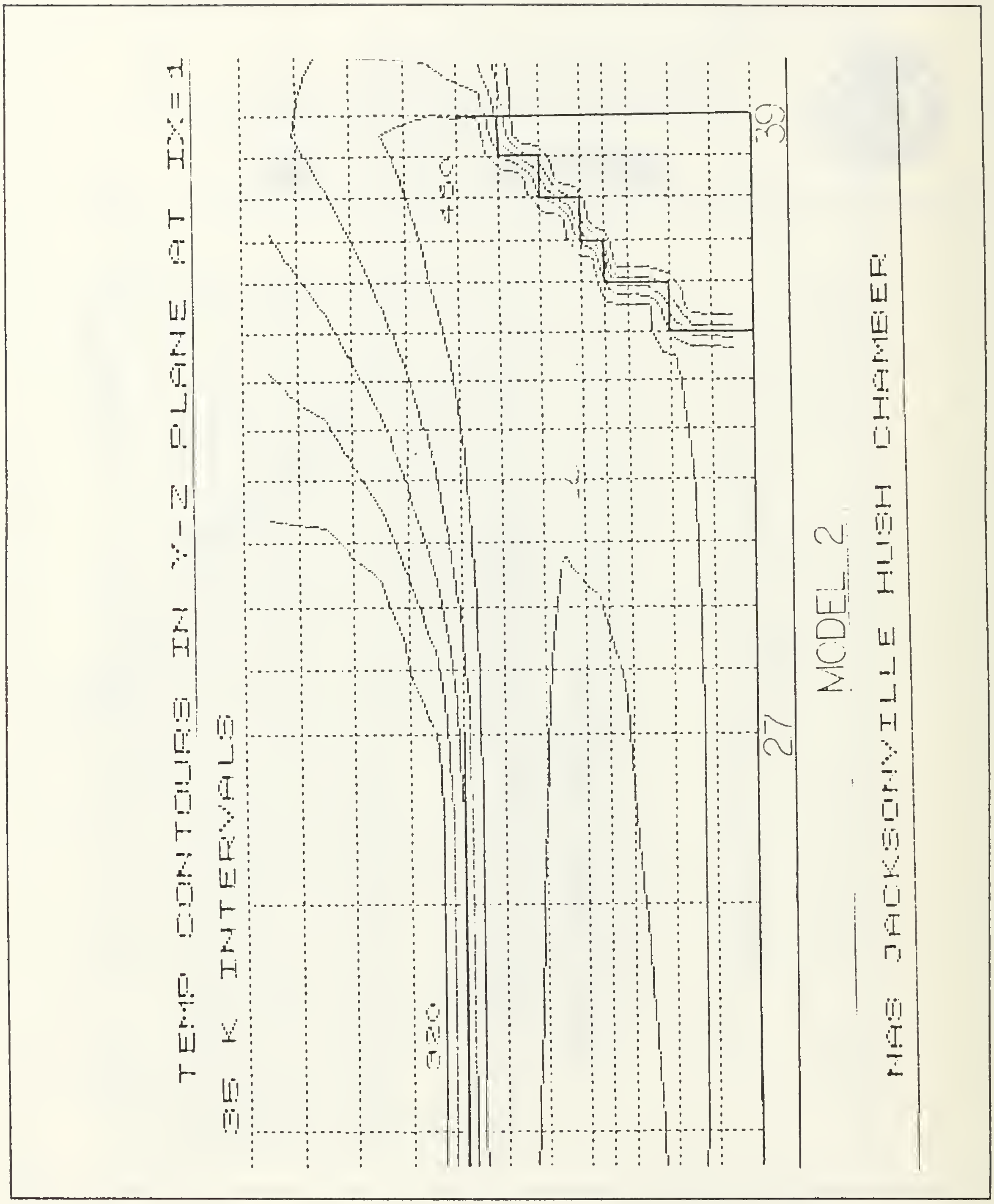

Figure 25. Temperature Contour for Model 2 (exhaust)

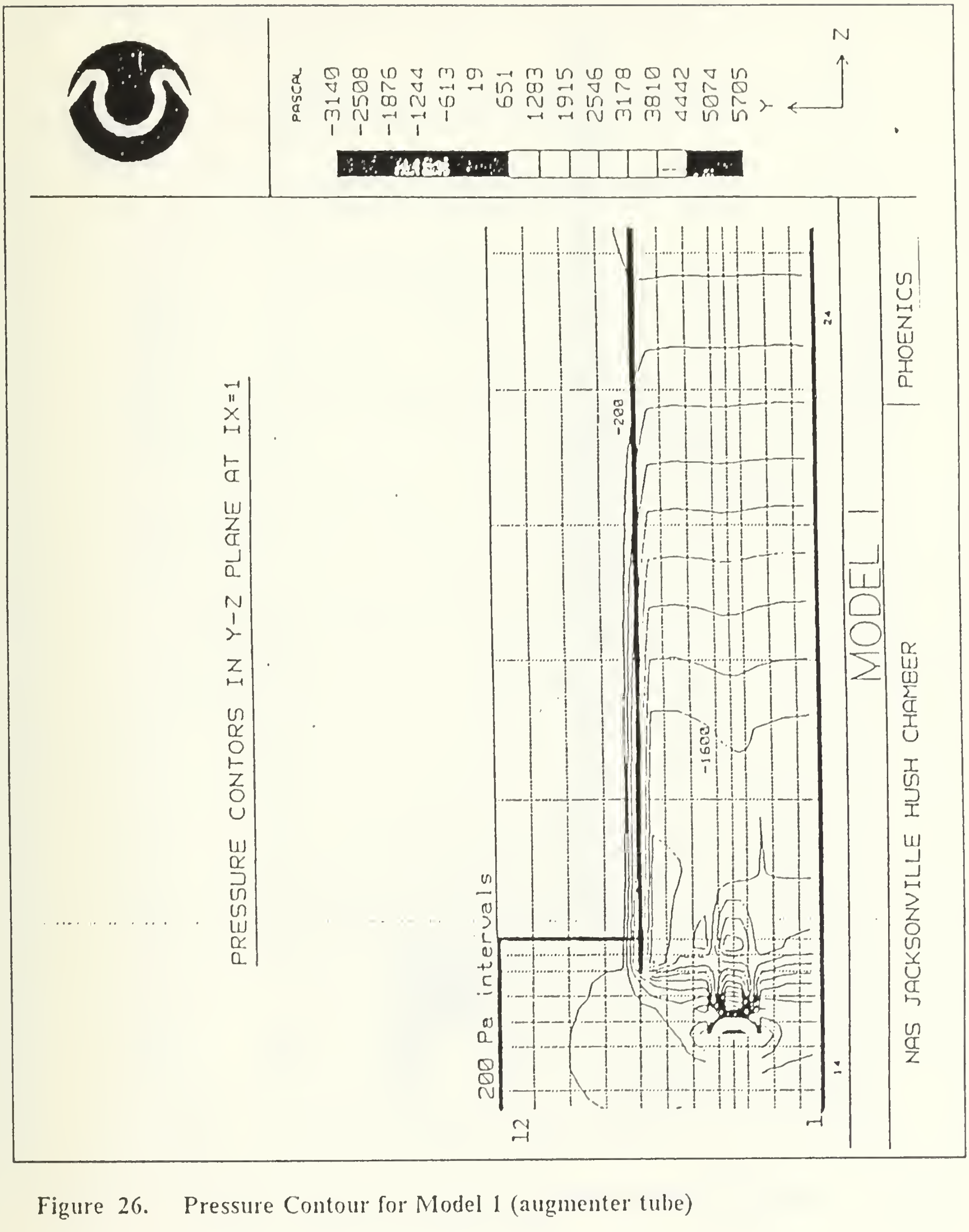

Figure 26. Pressure Contour for Model 1 (augmenter tube)

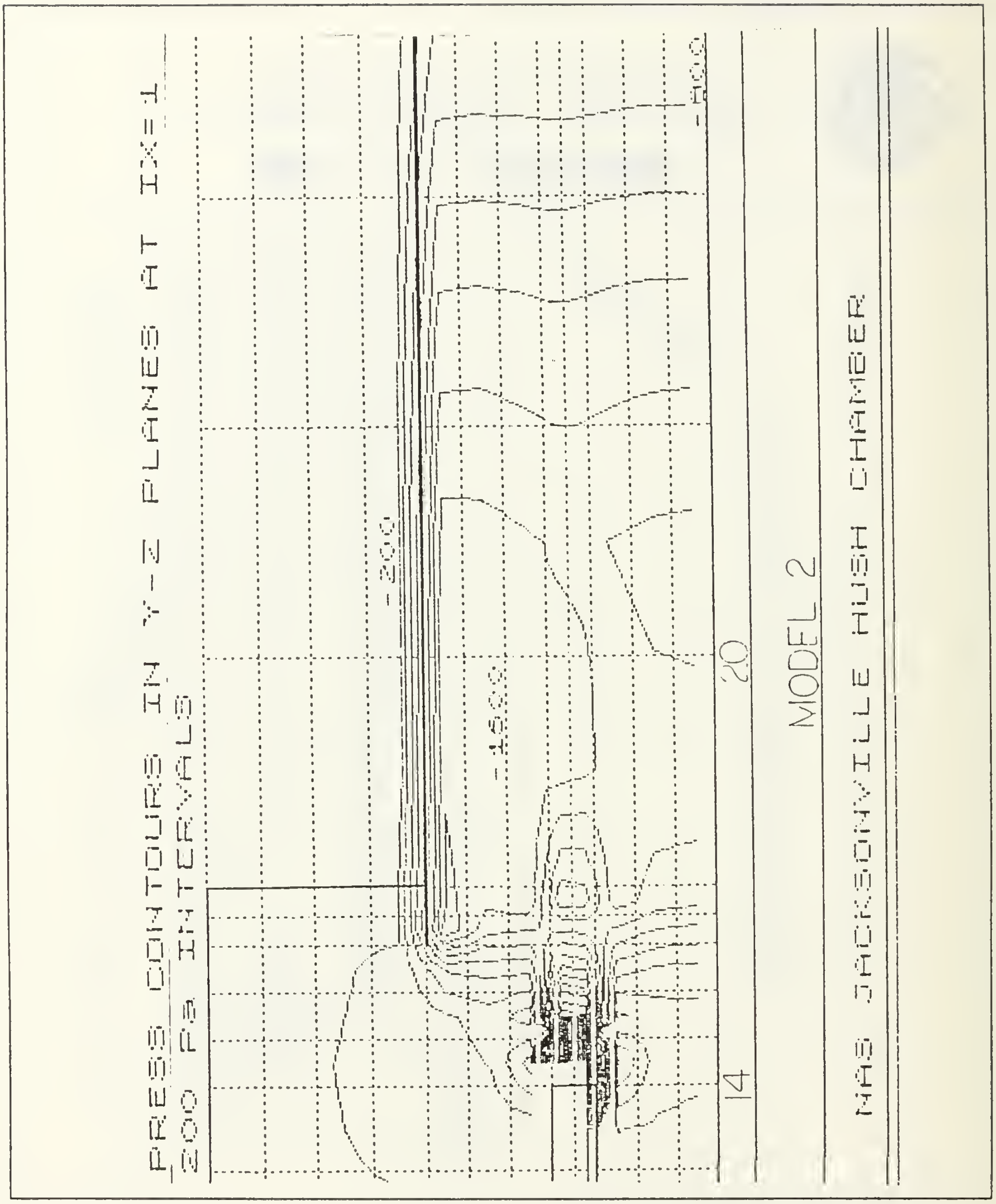

Figure 27. Pressure Contour for Model 2 (augmenter tube)

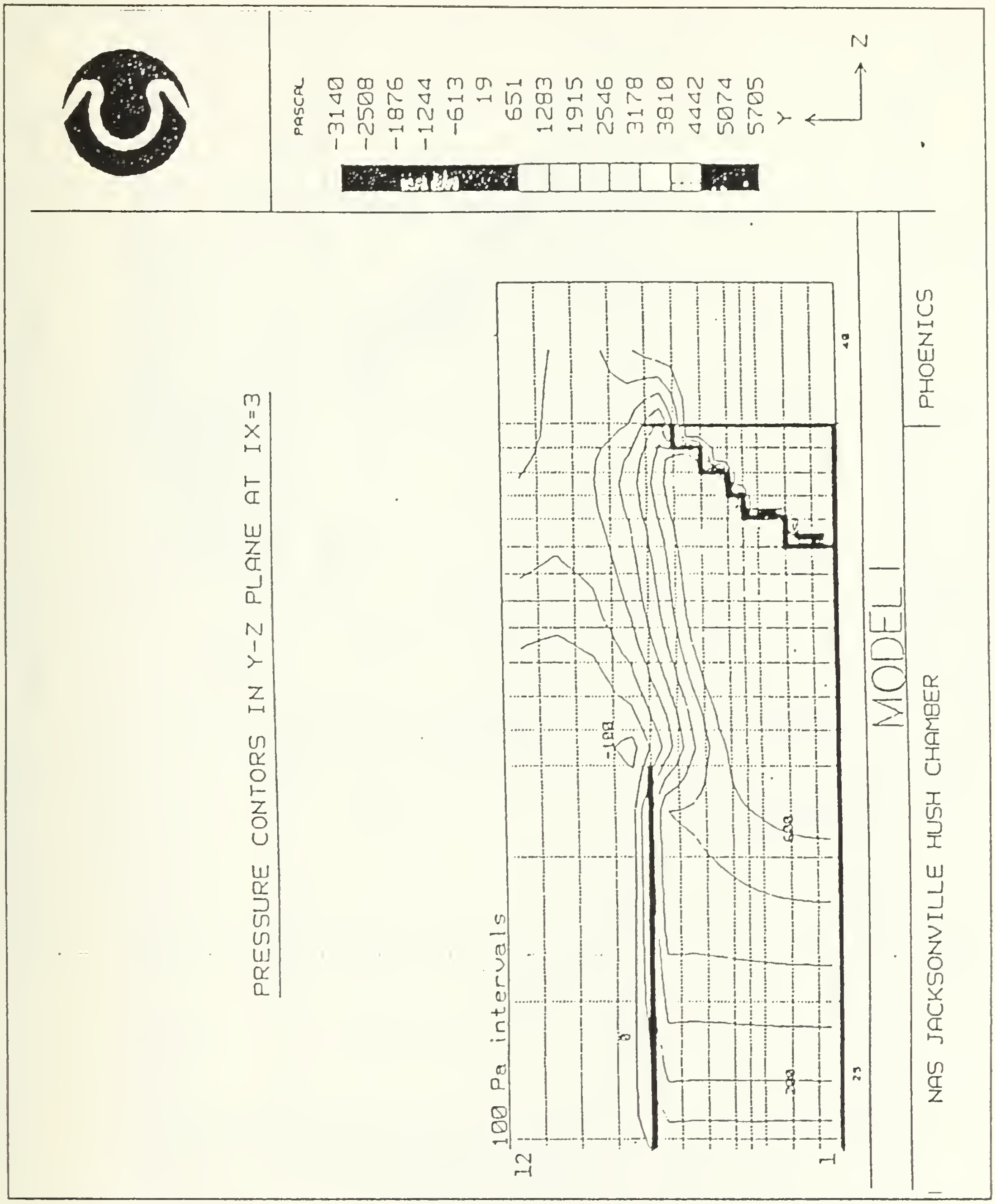

Figure 28. Pressure Contour for Model 1 (exhaust)

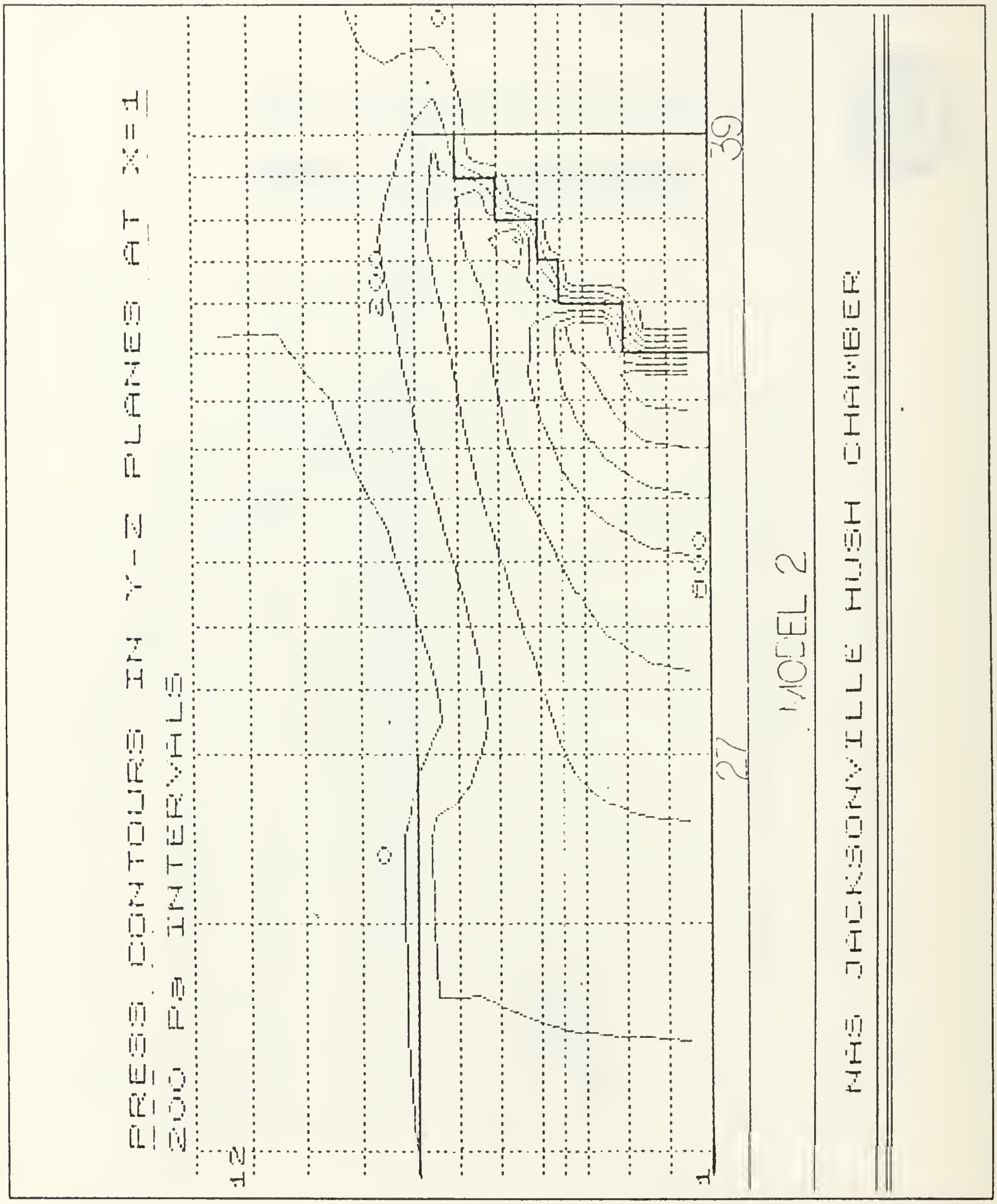

Figure 29. Pressure Contour for Model 2 (exhaust)

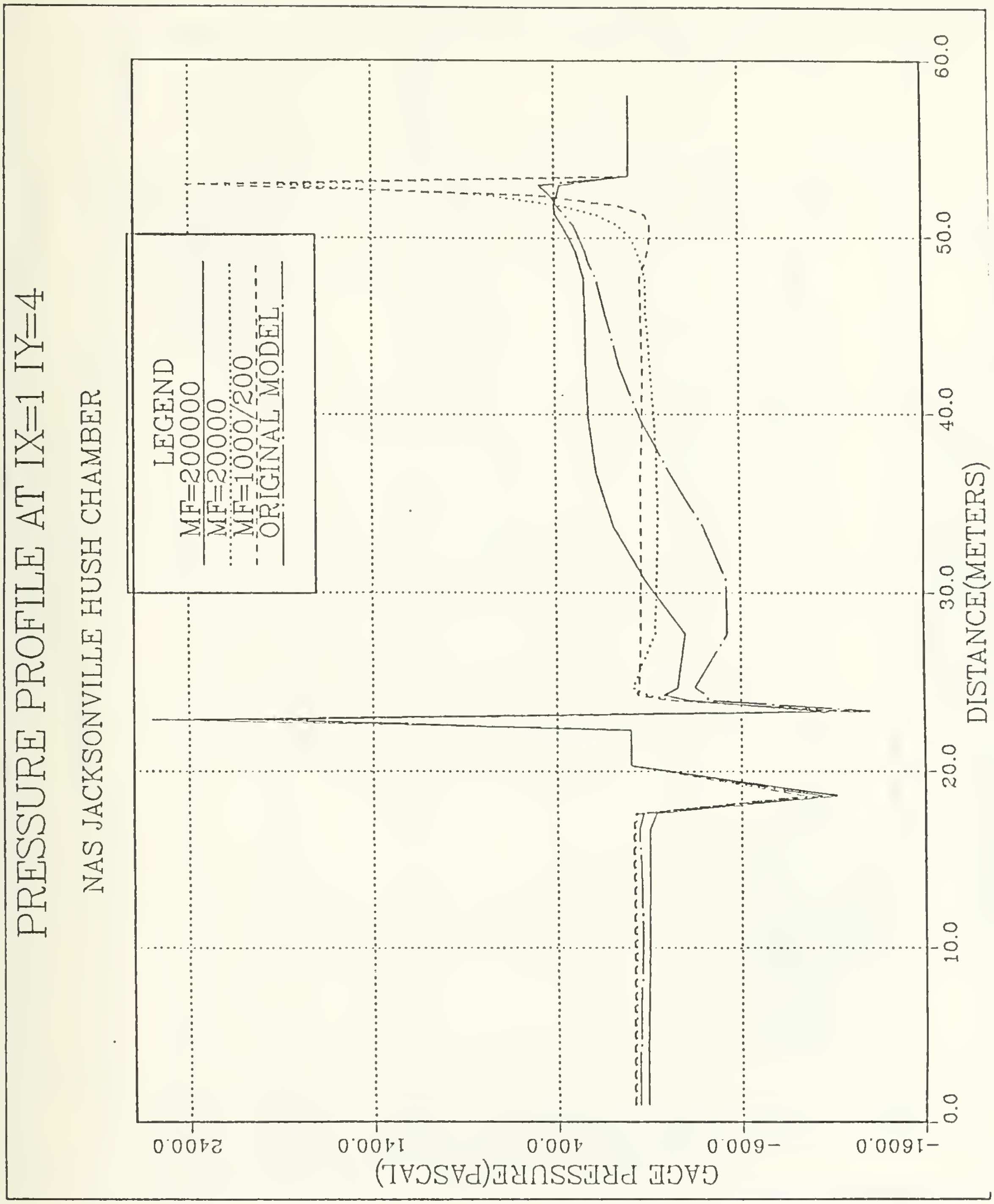

Figure 30. Turbulence Study Pressure Profiles

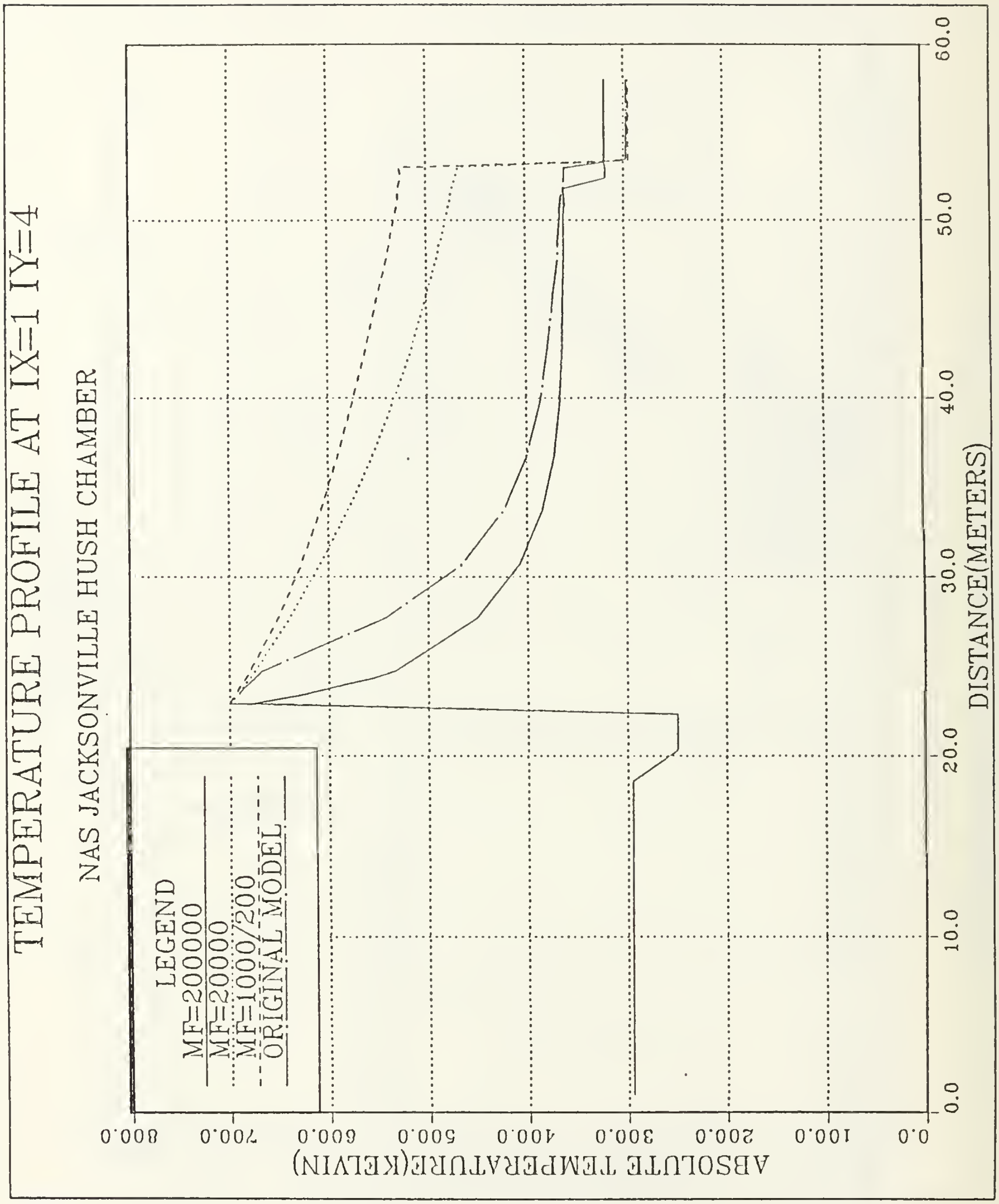

Figure 31. Turbulence Study Temperature Profiles

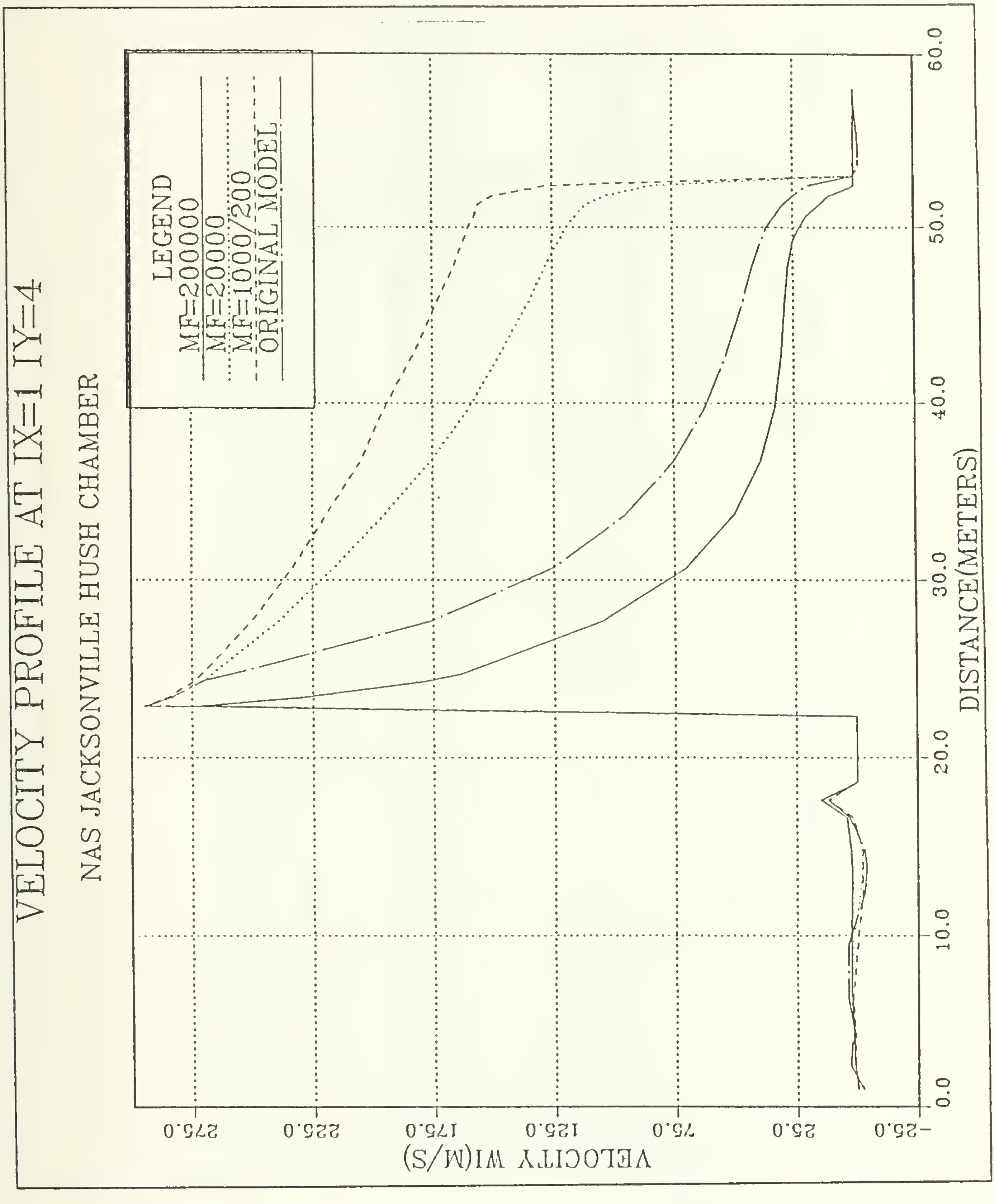

Figure 32. Turbulence Study Velocity Profiles

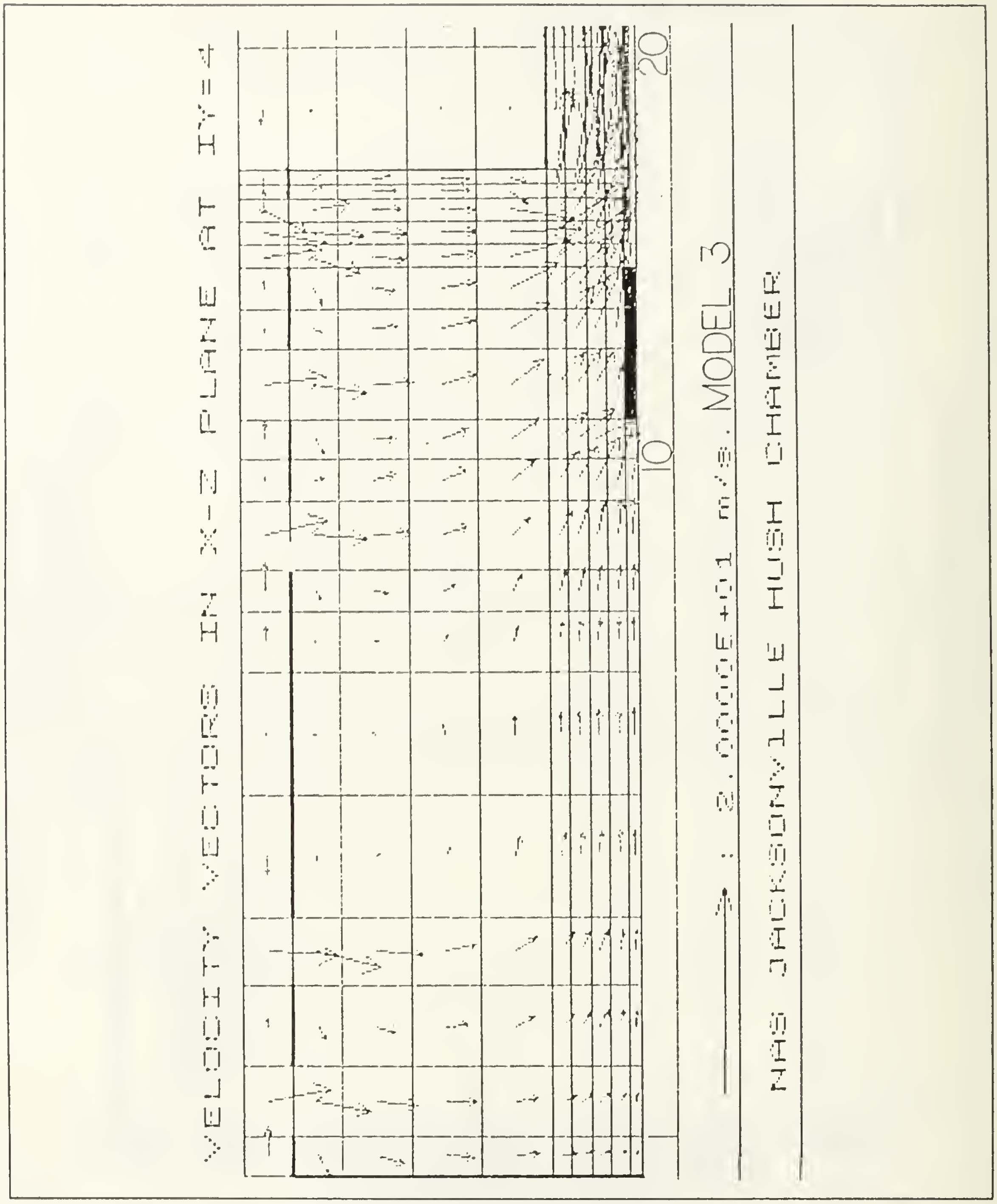

Figure 33. Velocity Vector Plot for Model 3 (test bay)

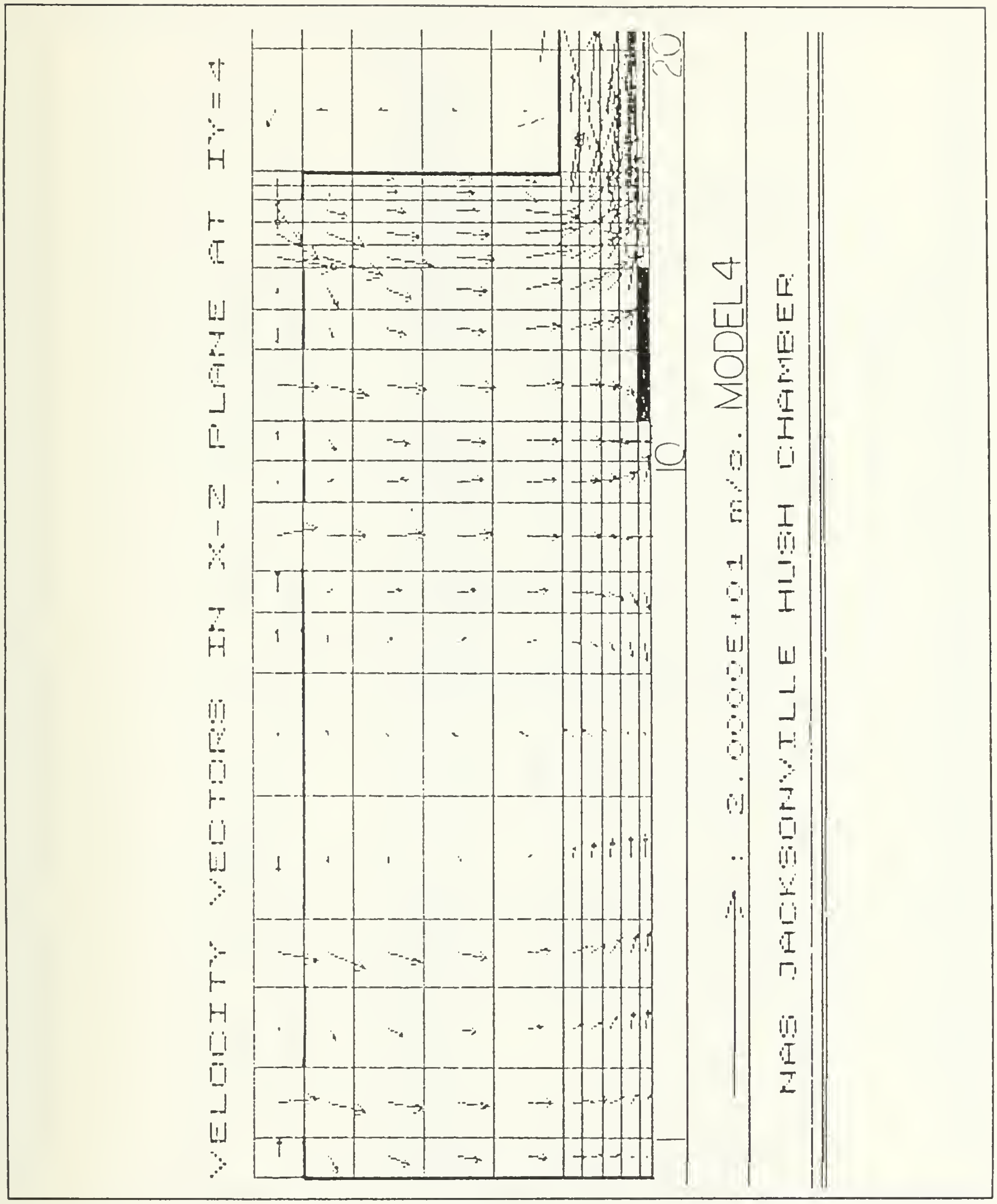

Figure 34. Velocity Vector Plot for Model 4 (test bay)

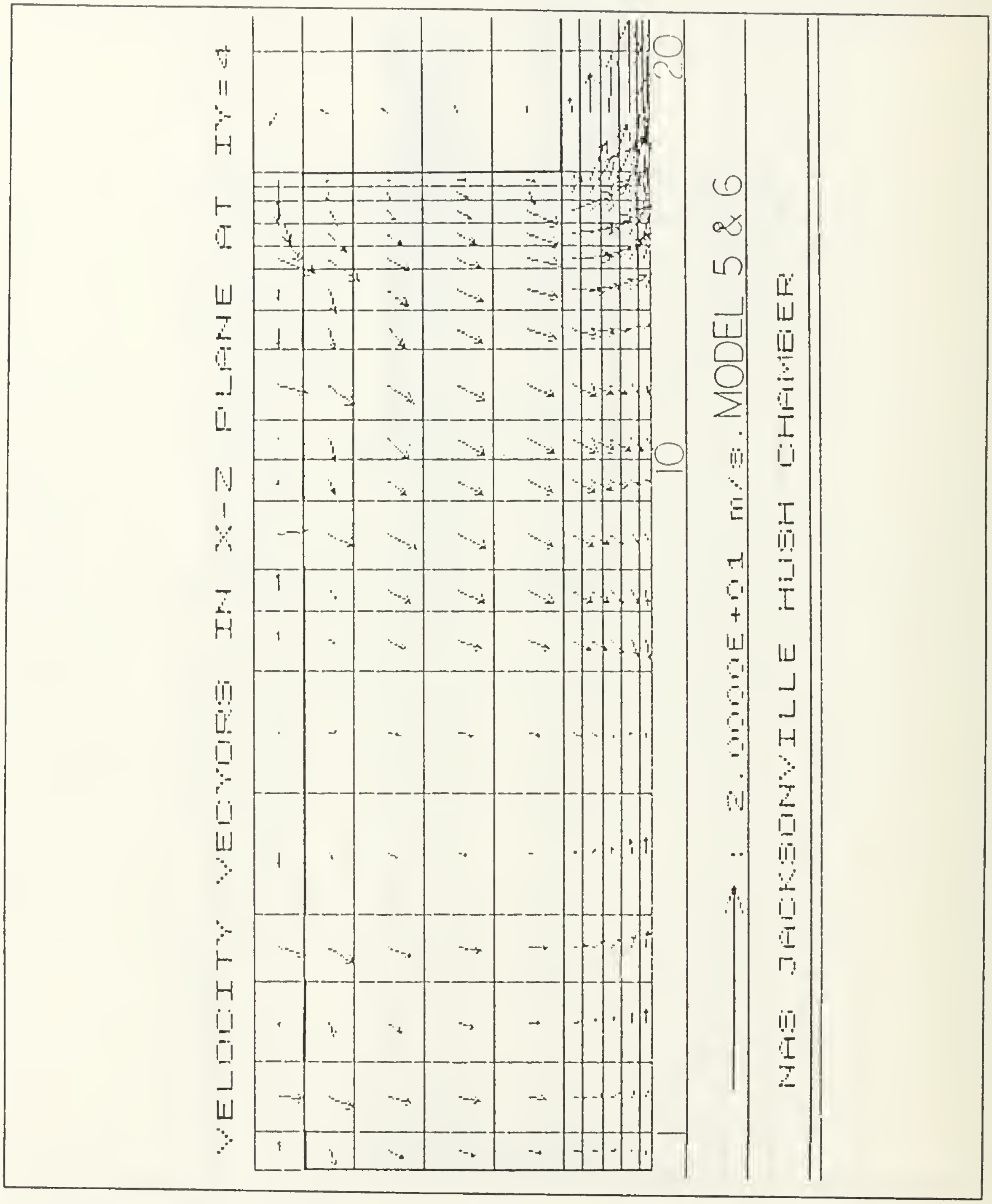

Figure 35. Velocity Vector Plot for Model 5 & 6 (test bay)

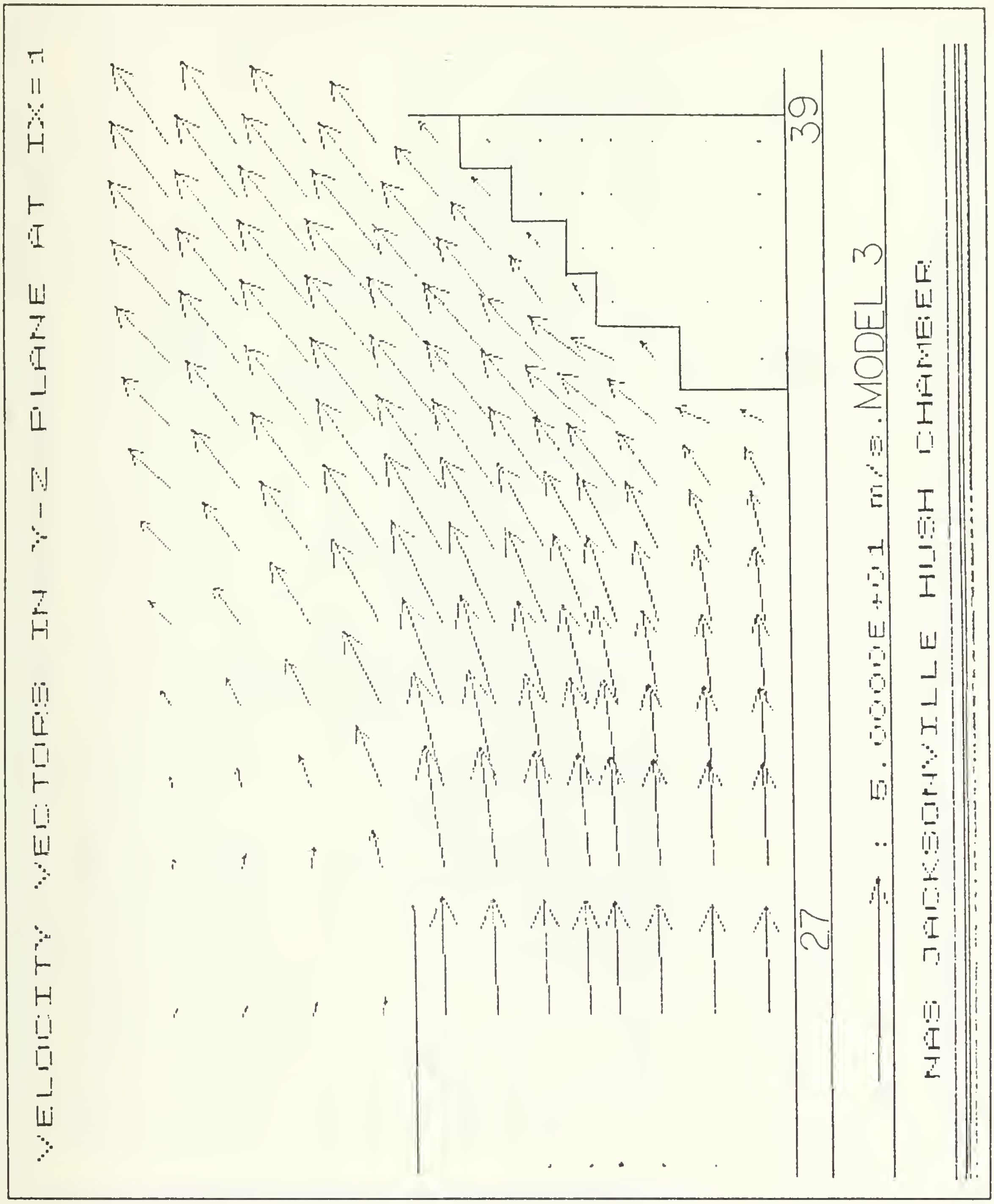

Figure 36. Velocity Vector Plots for Model 3 (exhaust)

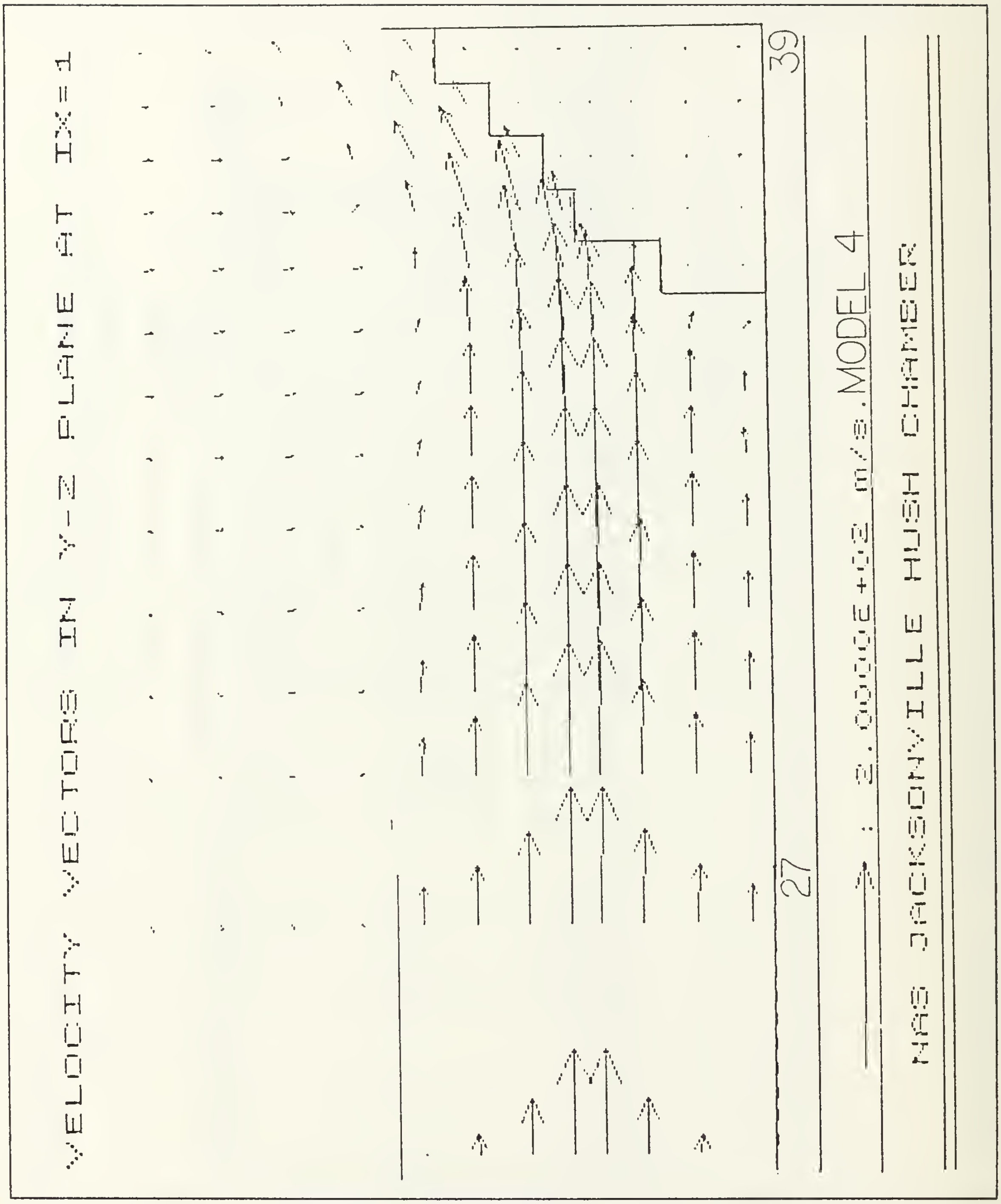

Figure 37. Velocity Vector Plot for Model 4 (exhaust)

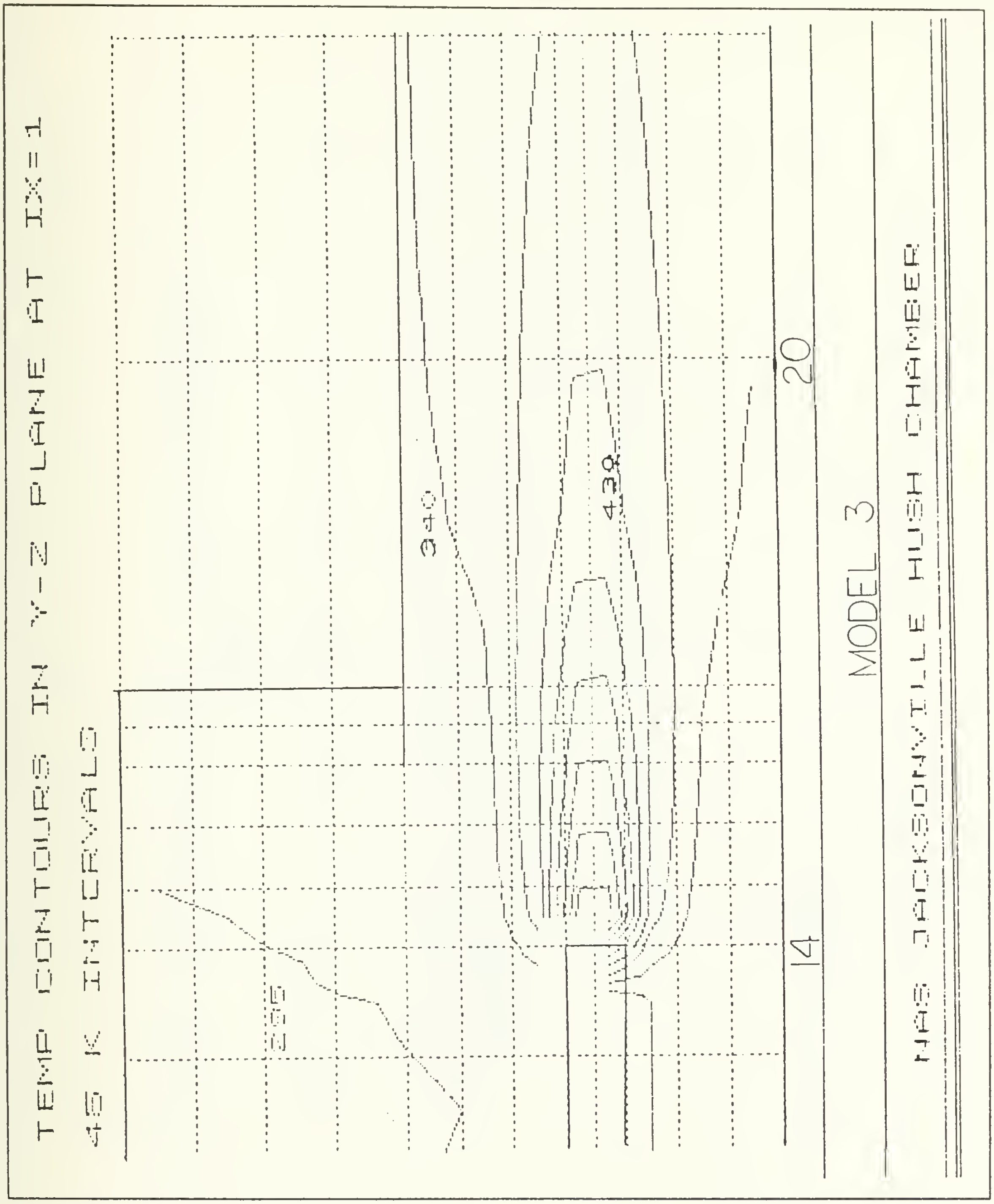

Figure 38. Temperature Contours for Model 3 (engine exhaust)

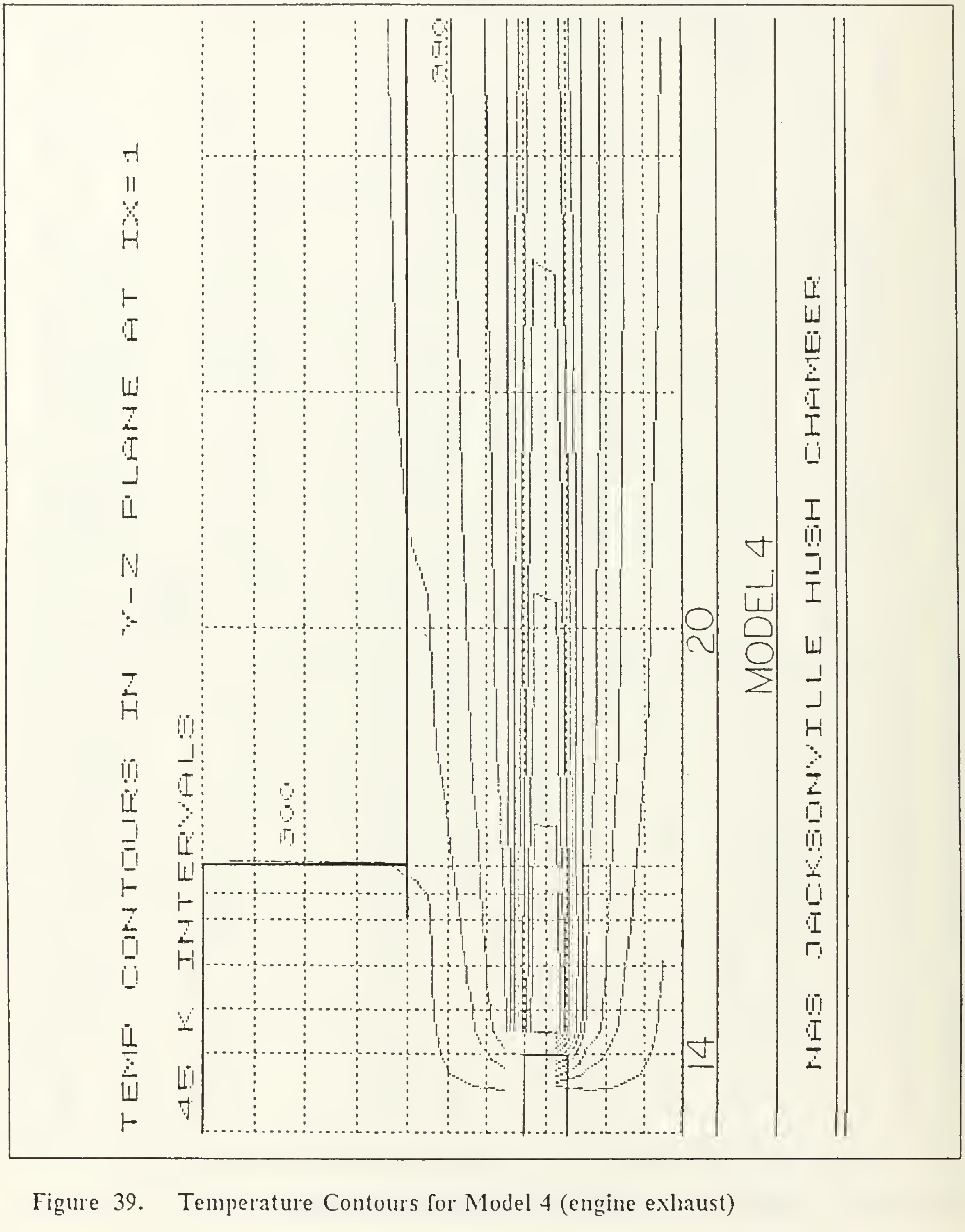

Figure 39. Temperature Contours for Model 4 (engine exhaust)

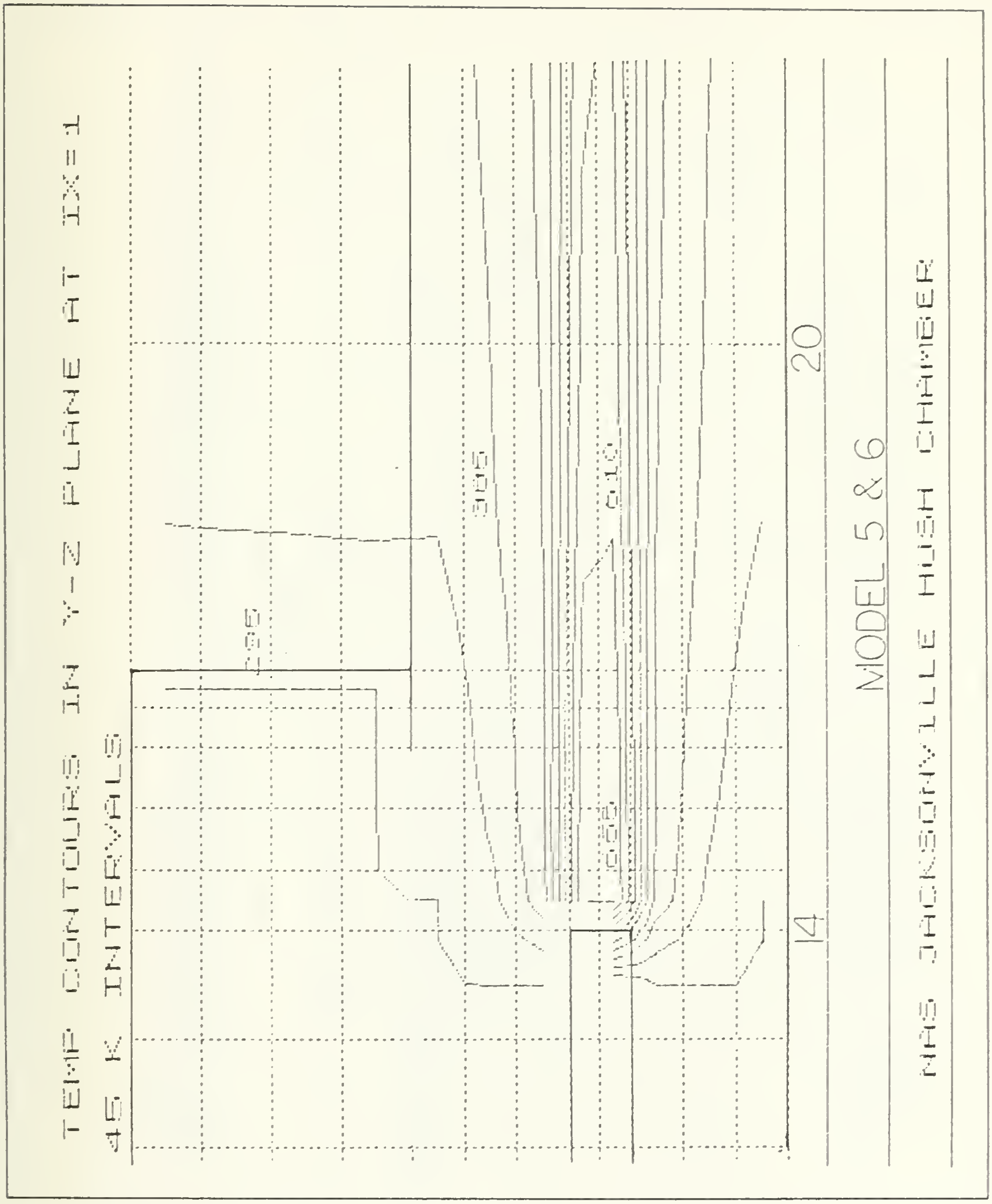

Figure 40. Temperature Contours for Model 5 & 6 (engine exhaust)

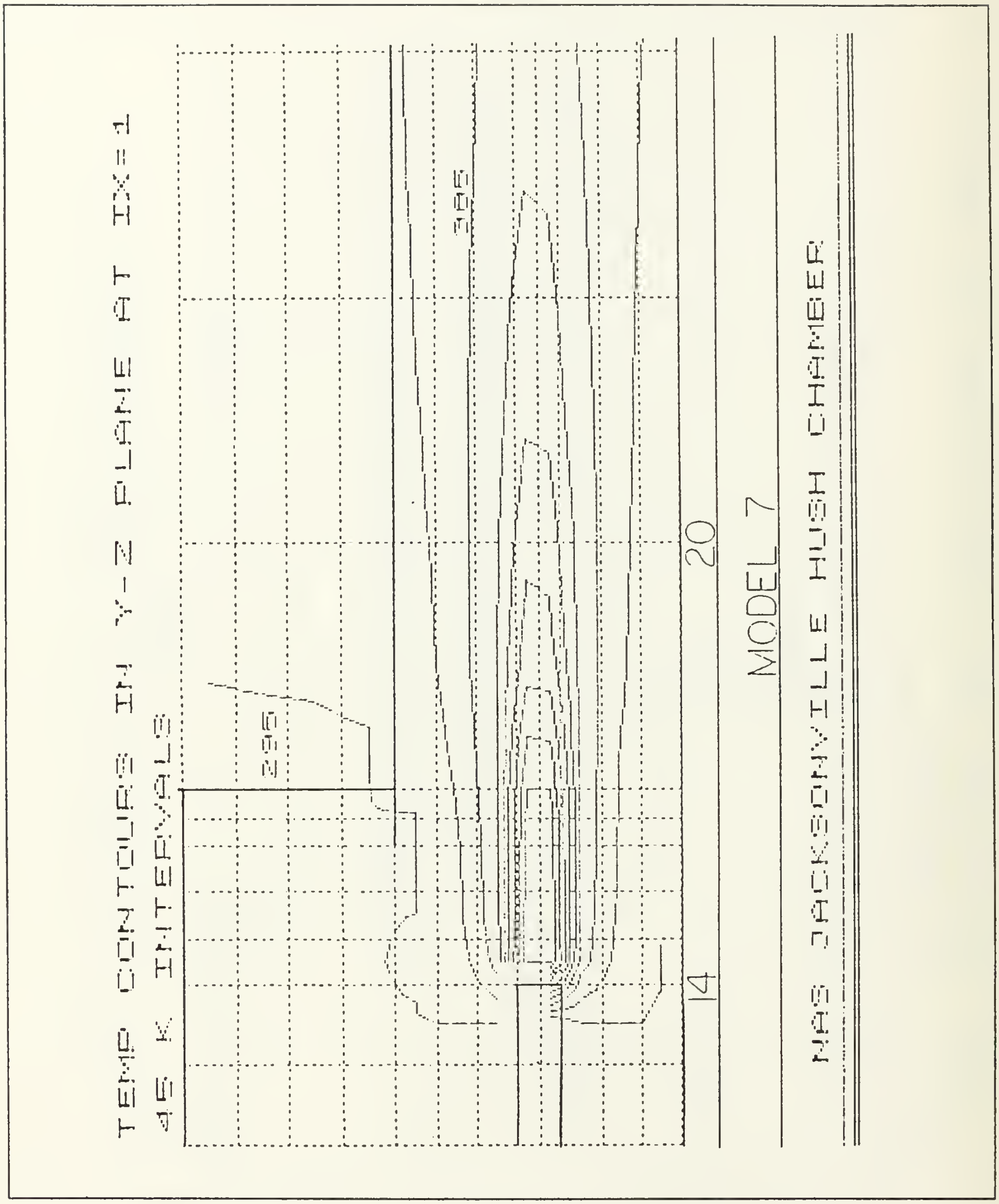

Figure 41. Temperature Contours for Model 7 (engine exhaust)

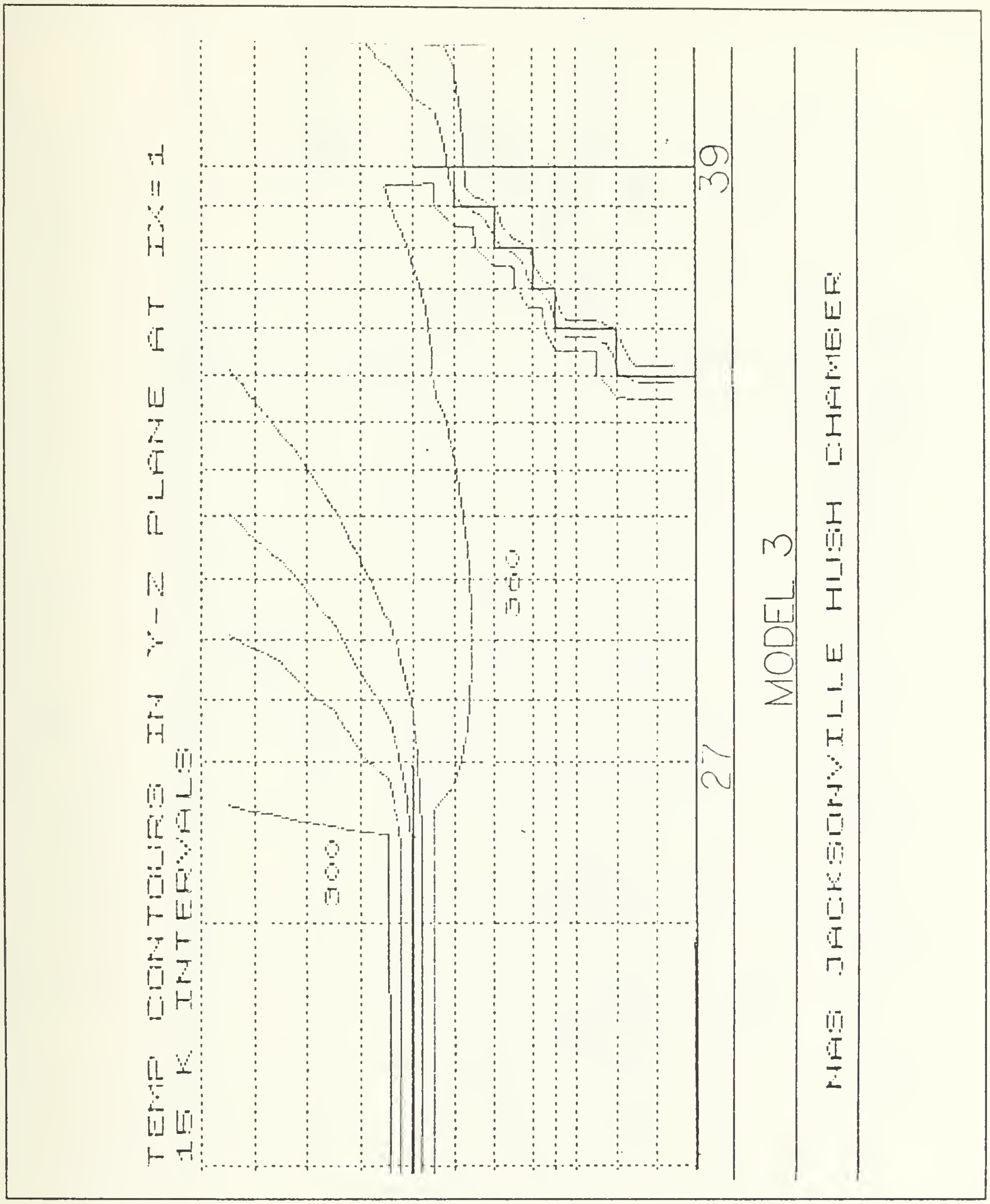

Figure 42. Temperatuer Contours for Model 3 (exhaust)

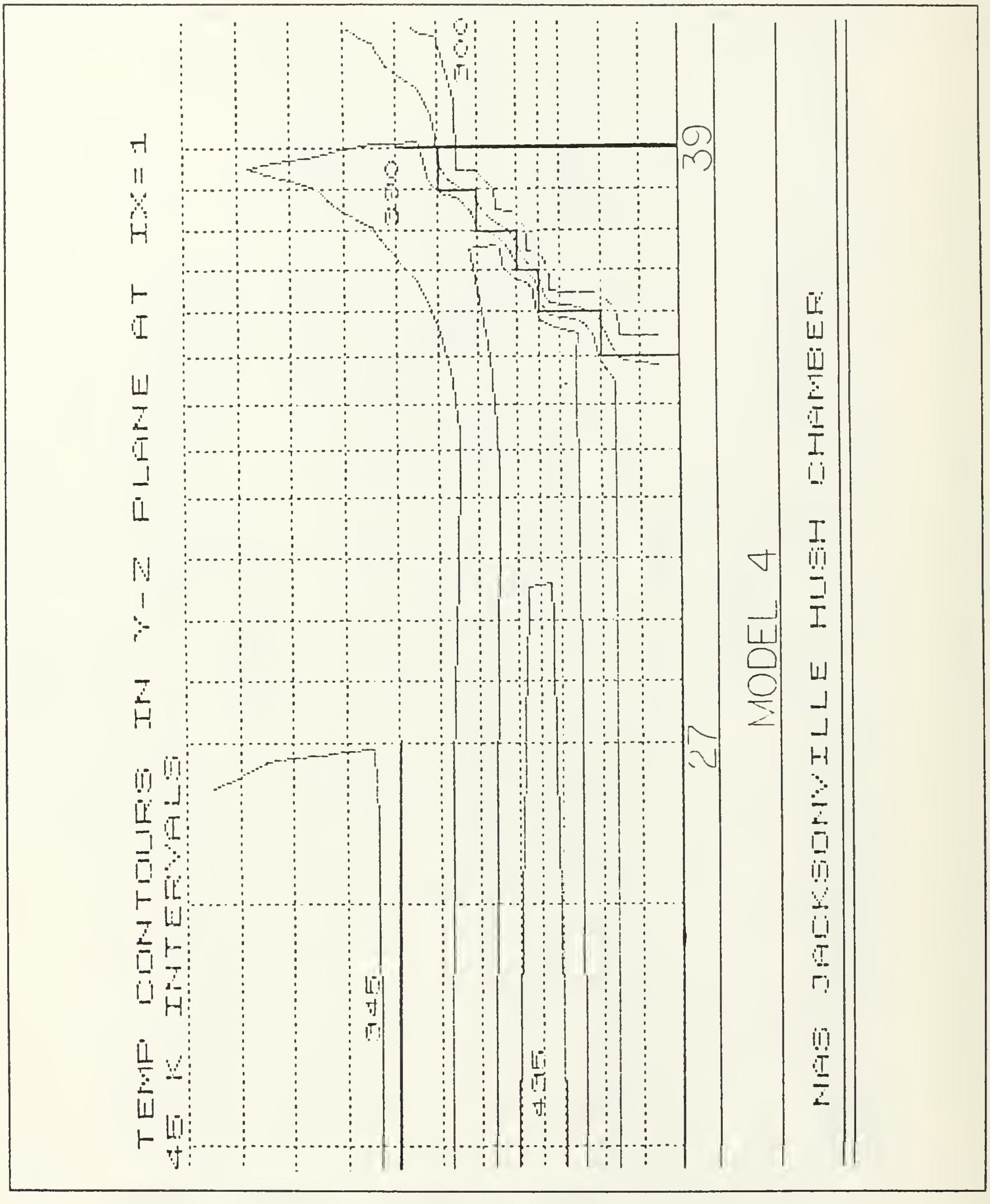

Figure 43. Temperature Contours for Model 4 (exhaust)

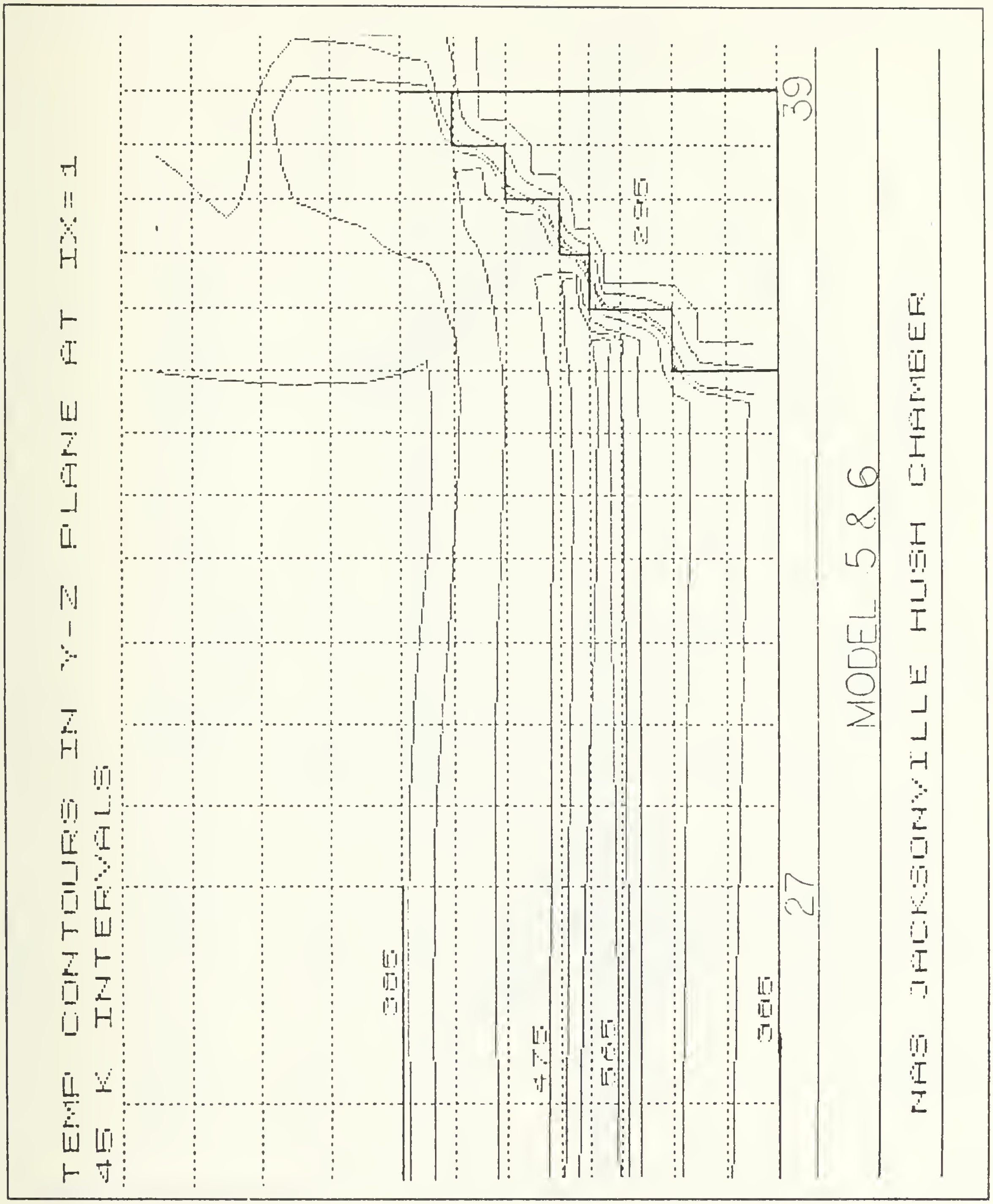

Figure 44. Temperature Contours for Model 5 & 6 (exhaust)

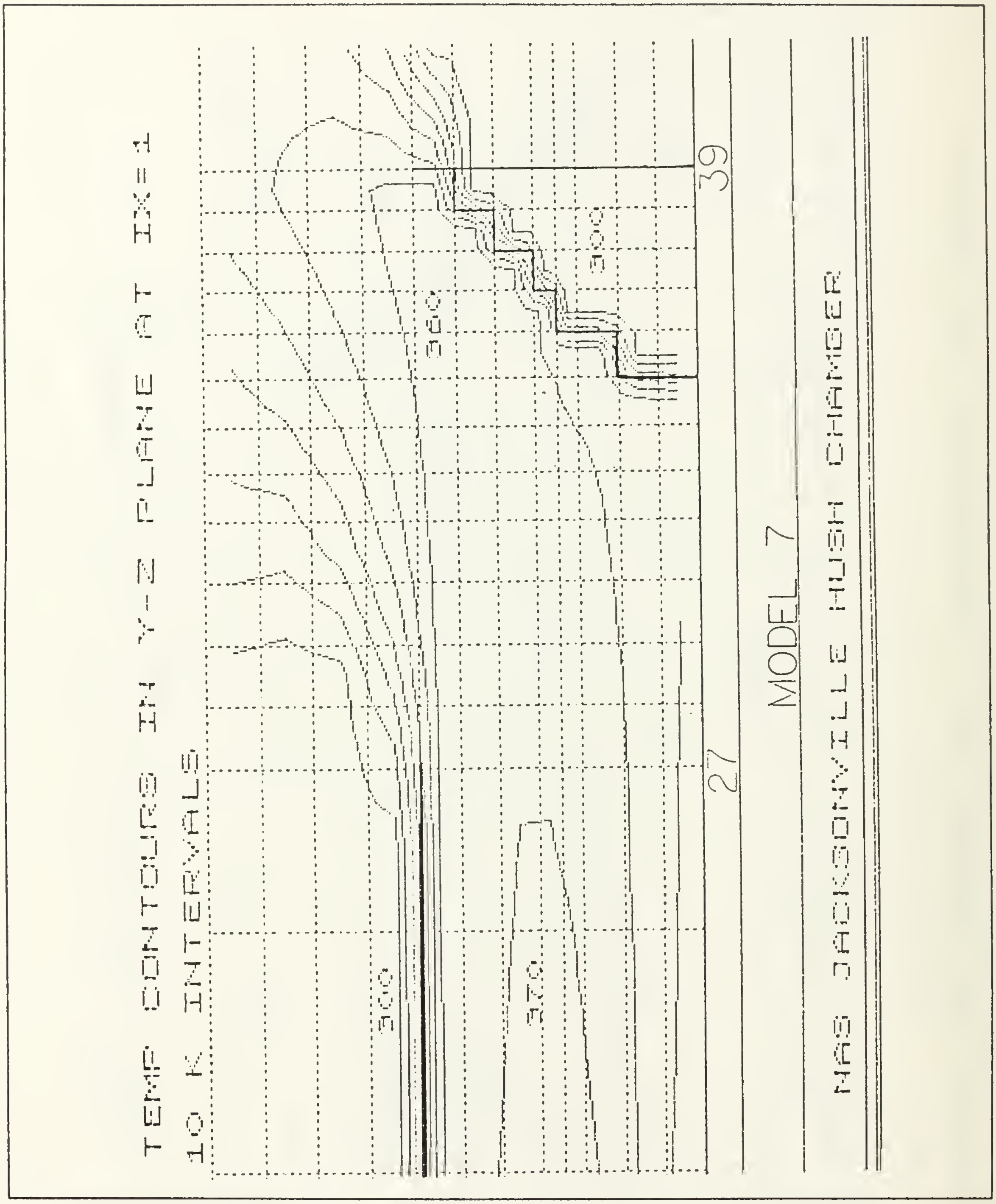

Figure 45. Temperature Contours for Model 7 (exhaust)

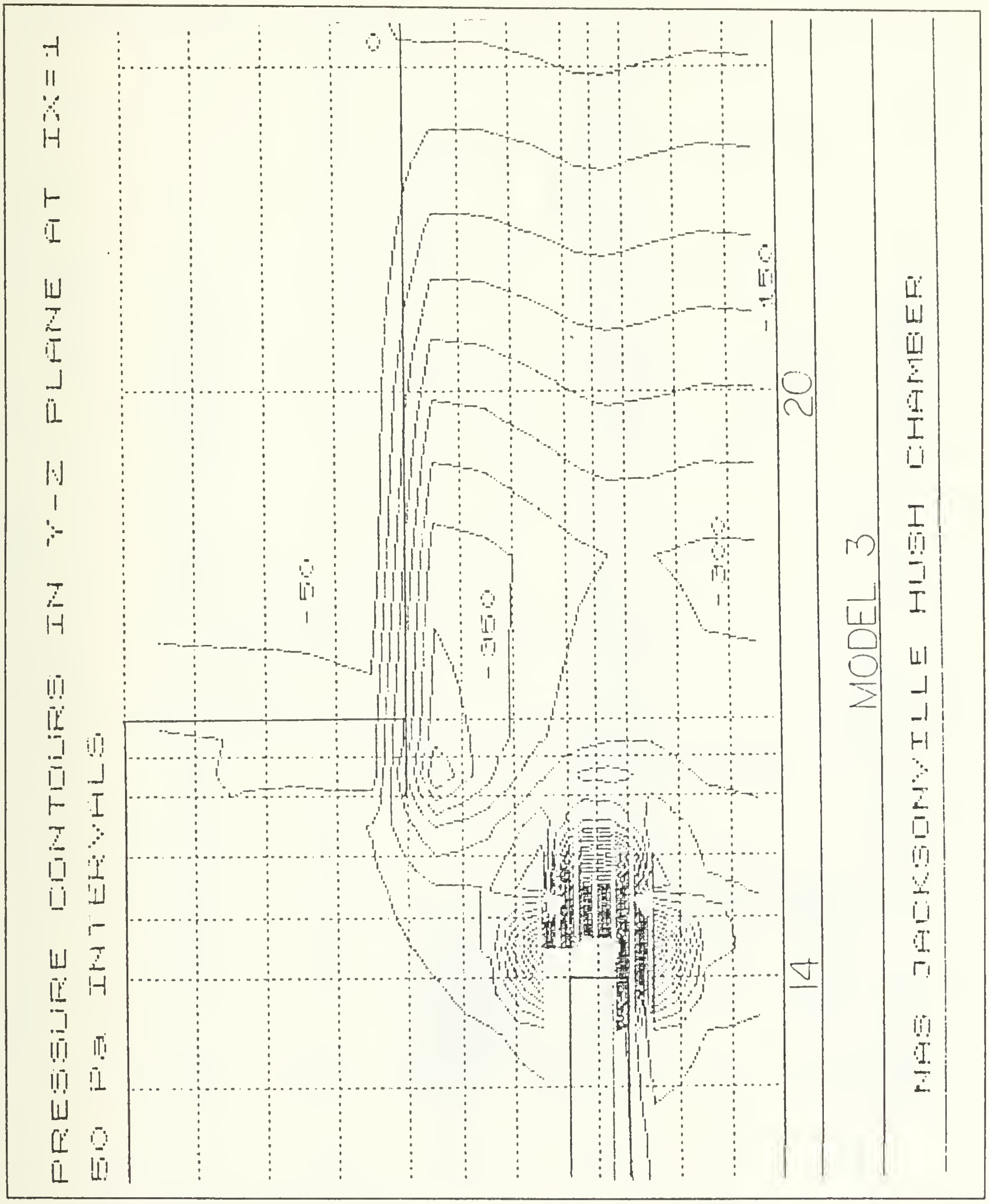

Figure 46. Pressure Contours for Model 3 (engine exhaust)

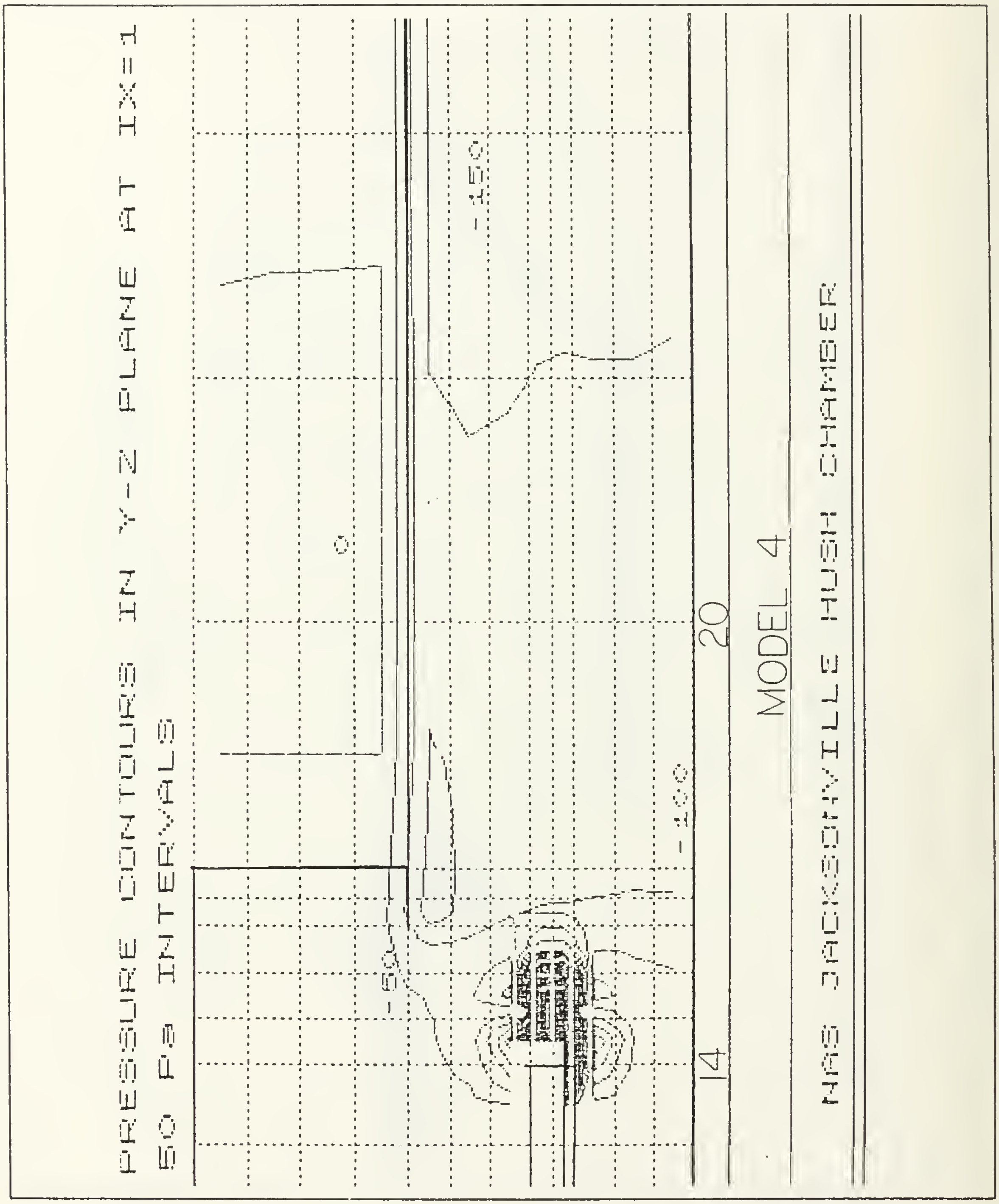

Figure 47. Pressure Contours for Model 4 (engine exhaust)

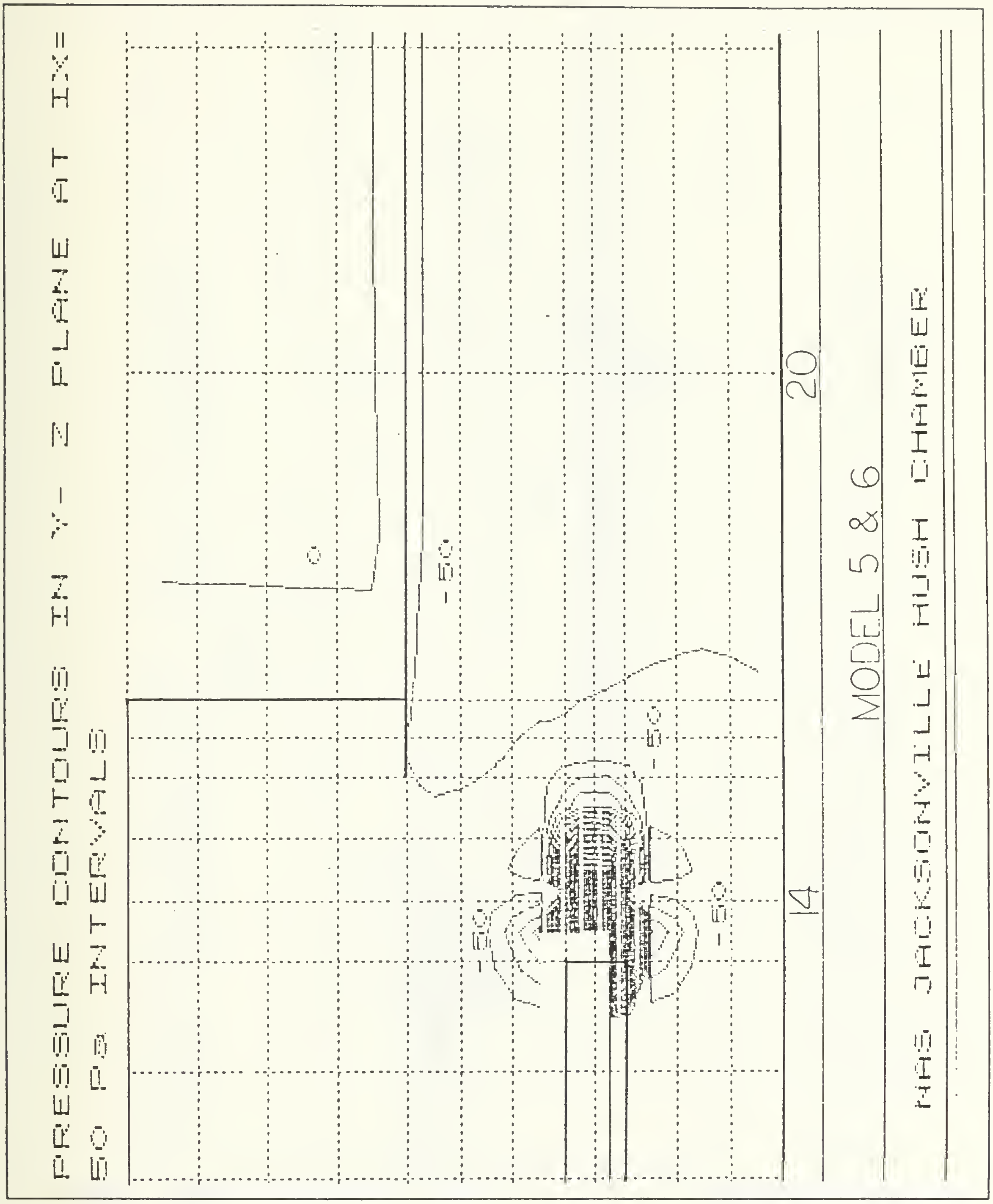

Figure 48. Pressure Contours for Model 5 & 6 (engine exhaust)

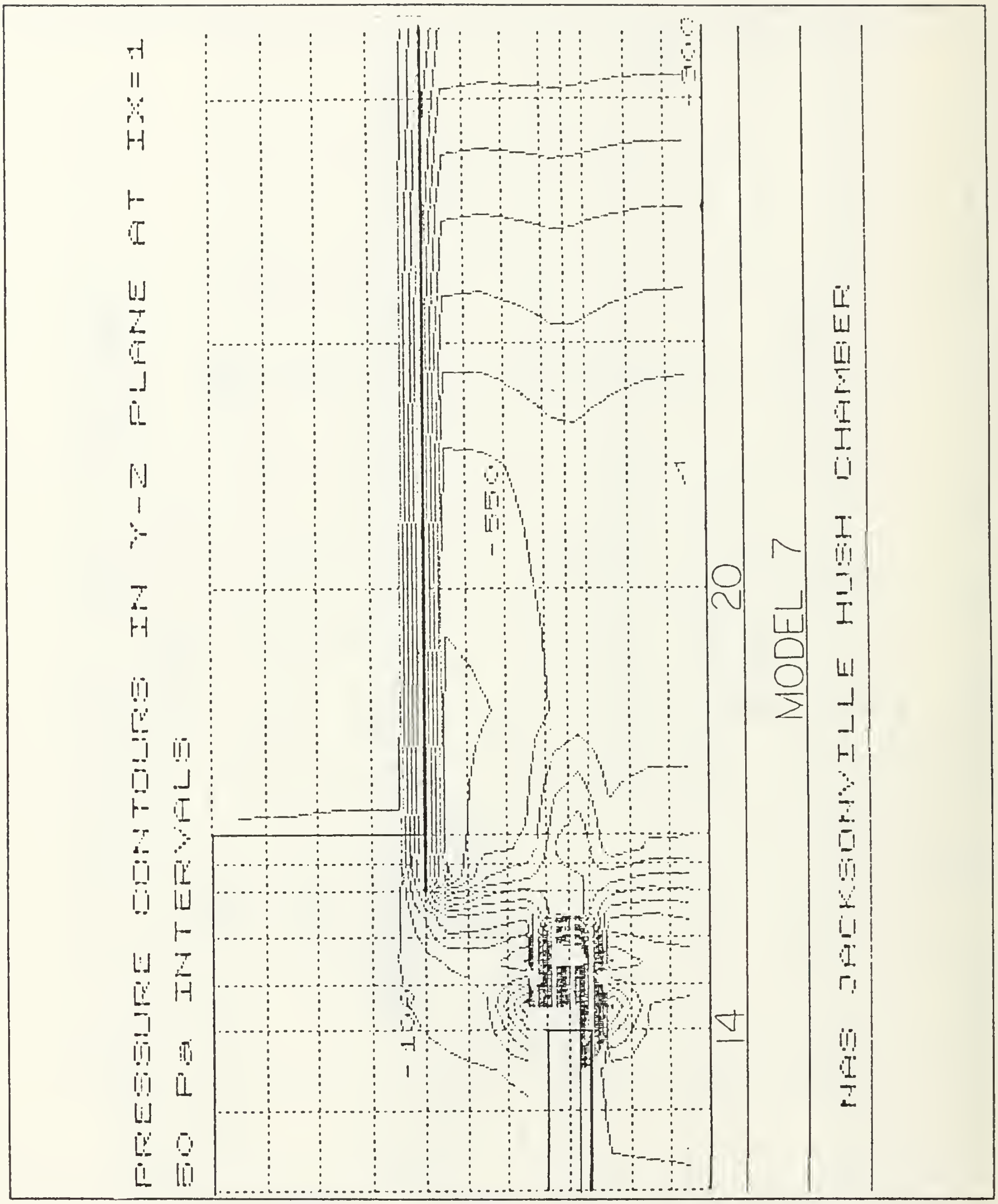

Figure 49. Pressure Contours for Model 7 (engine exhaust)

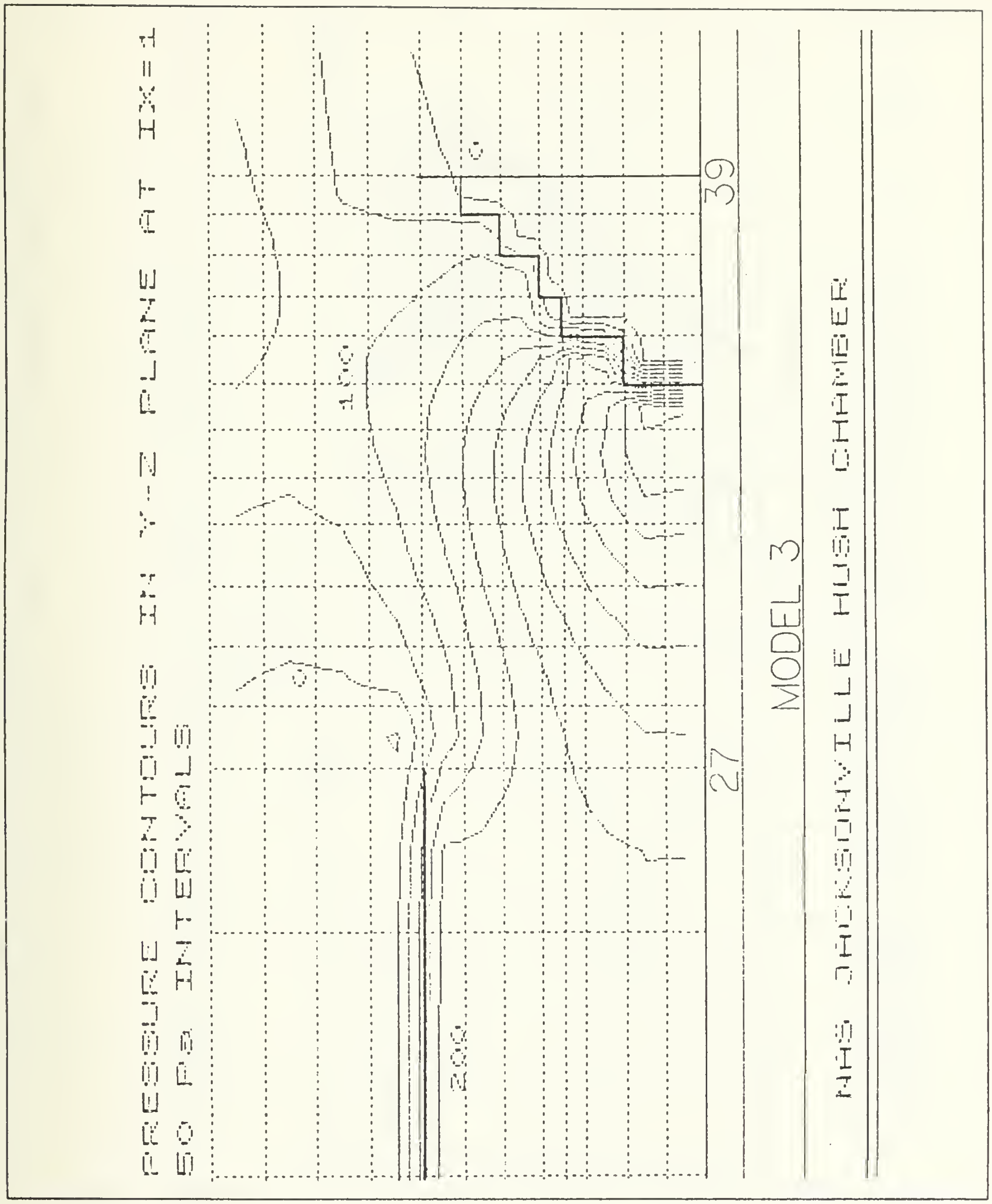

Figure 50. Pressure Contours for Model 3 (exhaust)

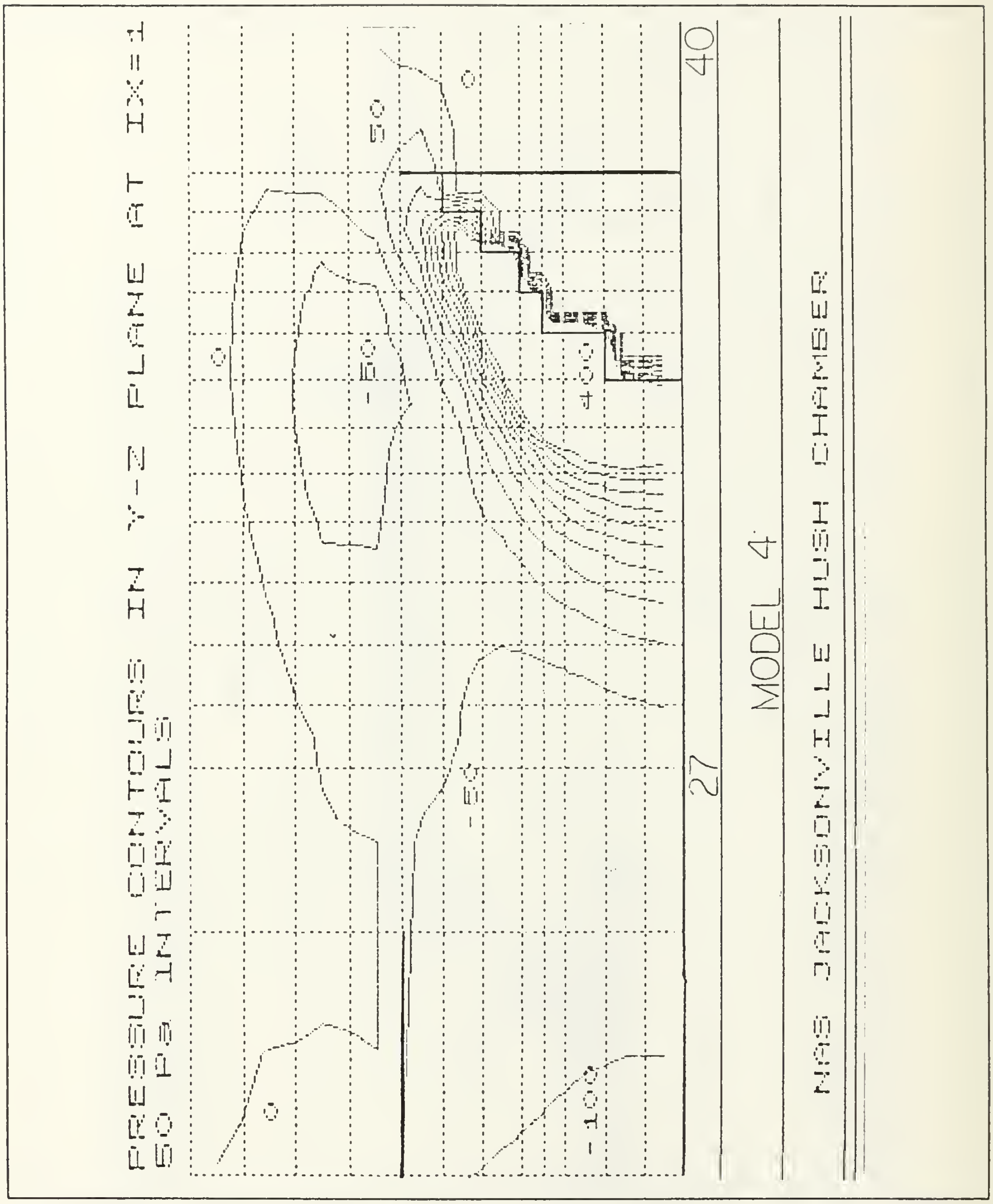

Figure 51. Pressure Contours for Model 4 (exhaust)

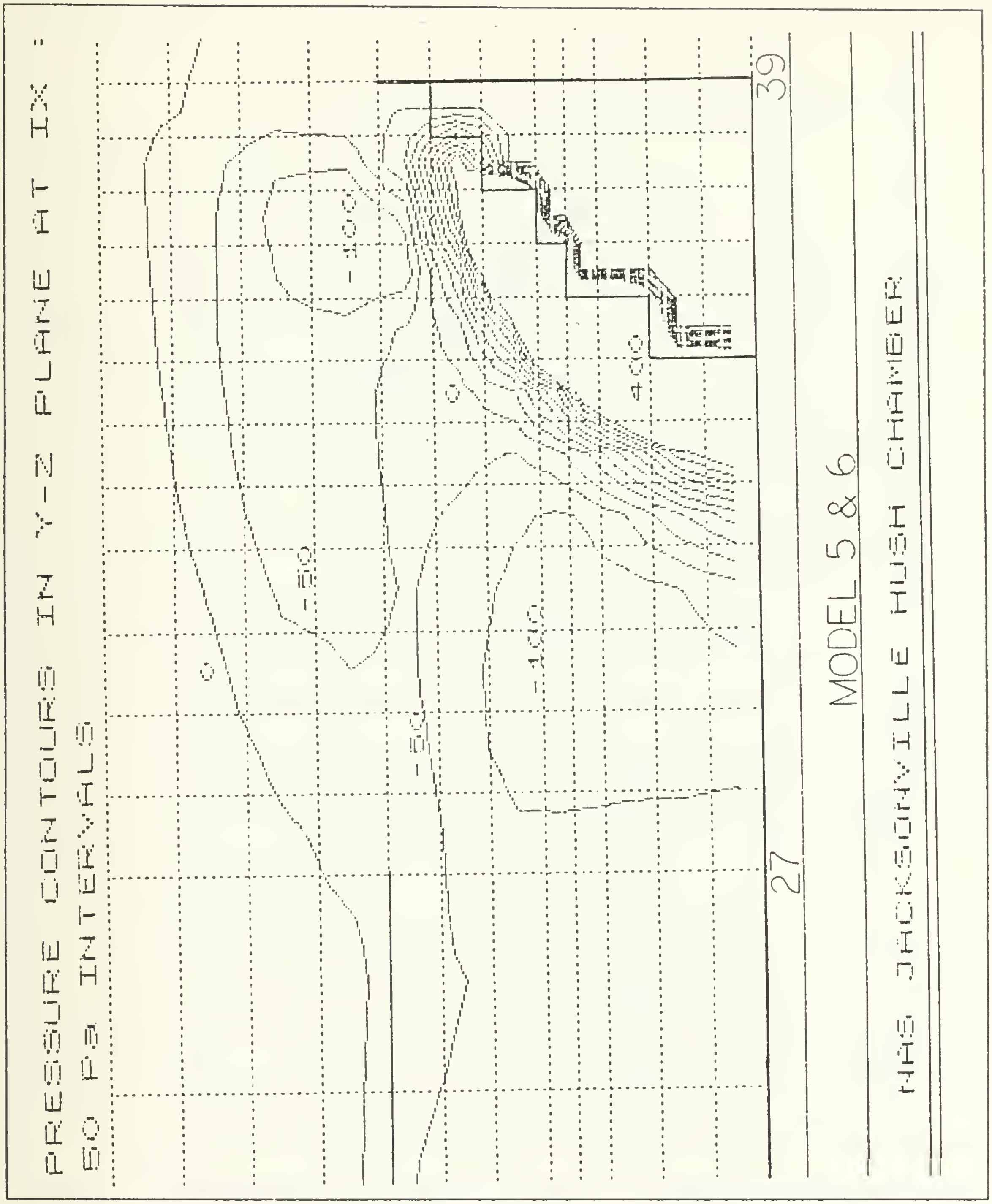

Figure 52. Pressure Contours for Model 5&6 (exhaust)

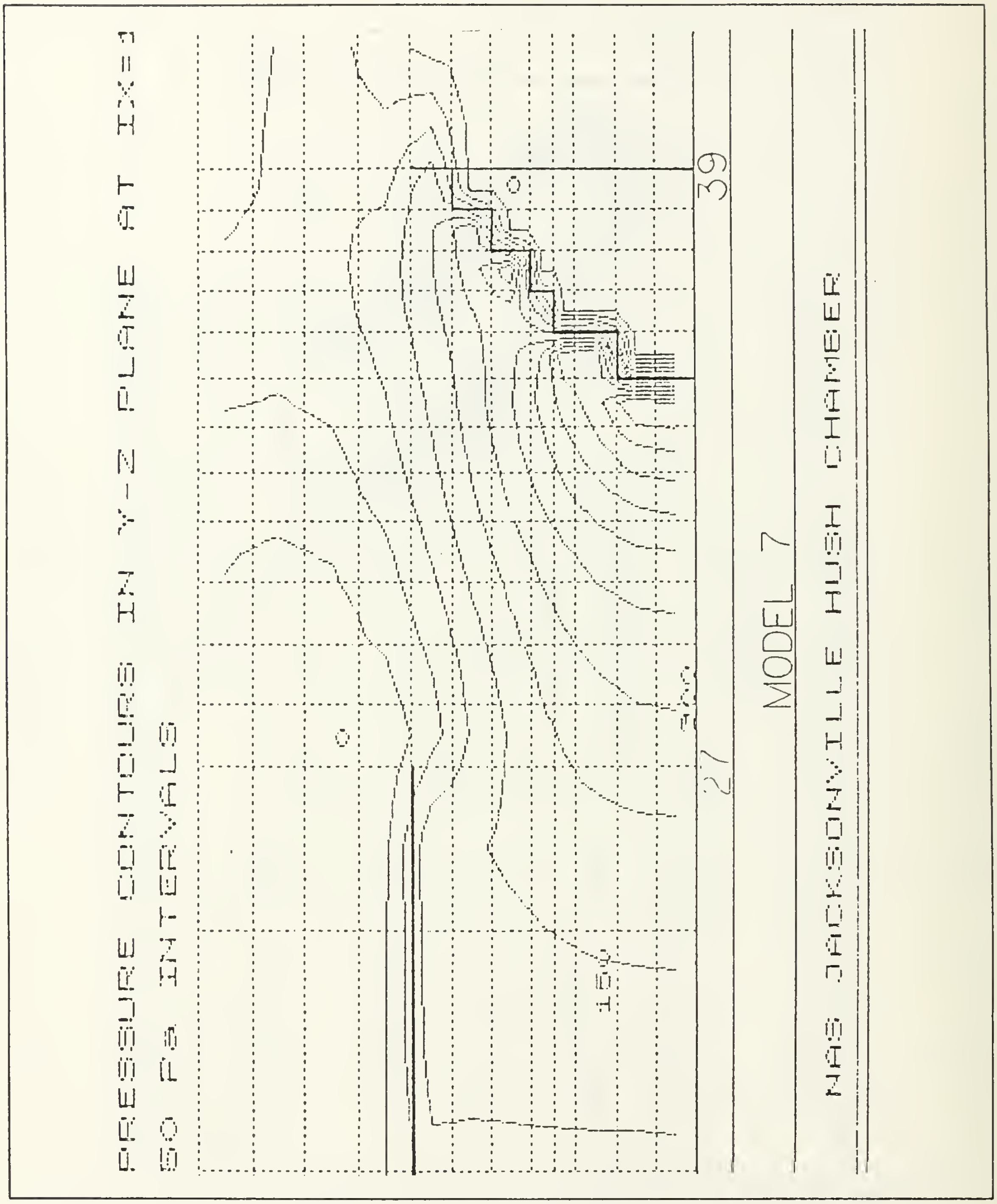

Figure 53. Pressure Contour for Model 7 (exhaust)

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Augmenter Tube Length Study

The results of the augmenter tube length parametric study shows no significant changes of pressure, temperature, or velocity fields when comparing the models with a 10% difference in augmenter tube length. System efficiency based on the augmentation ratio for the shorter augmenter tube model is 2% higher than in the original model. Unfortunately, it is likely that the sound level at the augmenter tube exhaust is inversely proportional to the augmenter tube length. That is, decreasing augmenter tube length will result in increasing noise levels. Existing jet engine test facilities barely meet, and in many instances exceed, acceptable noise level standards (85 dba at 200 feet from the test cell). Until a new cost effective acoustic absorption material with a higher coefficient of absorption is developed or a noise reduction system independent of augmenter tube length is developed the design of the Hush House incorporating a shorter augmenter tube would be conterproductive.

2. Turbulence Study

The selection of a turbulence model as initially expected has a dramatic effect on the final flow field solution.As the magnitude of the turbulent viscosity increases, the decrease of temperature and velocity through the augmenter tube increase. Halfway through the augmenter tube (Z distance = 39.7 meters) model ($v_T \approx 6.4$) has about a 50% reduction in temperature and about a 90% reduction in velocity compared with model 6 ($v_T \approx 0.01$) which has about a 20% reduction in temperature and about a 35% reduction in velocity. The effects of turbulent viscosity on the pressure distribution through the augmenter tube are not as clear cut as the effects of turbulent viscosity on temperature and velocity. The magnitude of the turbulent viscosity has a very significant effect on the pressure distribution but a simple correlation between the magnitude of the turbulent viscosity and the pressure distribution cannot be made.

It is interesting to note that in general, the results of model 7 (k- ε turbulence model) fall in a range between the results of model 3 and model 4. The magnitudes of the turbulent viscosity ENUT in the arbitrilly selected cell defined by IX-1, IY-4, and IZ=20 for model 3, model 7, model 4, and model 5 are as follows:

ENUT for model 3 = $6.4\frac{Ns}{m^2}$

ENUT for model 7 = $4.4\frac{Ns}{m^2}$

ENUT for model 4 = $1.1\frac{Ns}{m^2}$

ENUT for model 5 = $0.06\frac{Ns}{m^2}$

The approximate value of ENUT = 4.4 for model 7 can be arrived at with the multiplying factor MF in equation (3.10) set to the order of 80,000. That is the k- ε model results could be approximated by the temperature dependent turbulence model by proper setting of MF in equation (3.10).

This turbulence study was not intended to determine a turbulence model that most closely simulated the actual flow field in the Hush House. The study was intended to simply show how different turbulent viscosity models effected the flow field. The study shows that to obtain a good numerical solution using PHOENICS, it is necessary to obtain more experimental data in order that the best turbulence model is incorporated in the PHOENICS simulation.

B. RECOMMENDATIONS

The final objective is to develop a valid computer model of the Naval Air Station Jacksonville, Florida Hush House. Two major stumbling blocks must be overcome in order to attain the final objective. The first and foremost is to obtain more pressure, temperature and velocity data from the augmenter tube of the actual Hush House. At present, temperature and velocity data is available for only one location in the augmenter tube. The number of locations for collecting the data must be sufficient to show accurate pressure, temperature, and velocities profiles through the augmenter tube. Once the data is obtained the PHOENICS generated pressure, temperature, and velocity profiles should be matched to the actual profiles by manipulating the magnitude of the multiply factor MF in the temperature dependent turbulence model. The temperature dependent turbulence model is recommended over other turbulence models for future use in model simulations of the Hush House due to the relative ease of being able to match model results to actual Hush House data.

APPENDIX A. "Q1" FILE (TURBULENCE STUDY)

```
*******************************************************************
*   NAVAL AIR STATION JACKSONVILLE FLORIDA HUSH HOUSE TEST        *
*   FACILITY. THESIS PROJECT OF LT ERIC A. NICOLAUS USCG          *
*   WITH THESIS INSTRUCTOR PROF DAVID SALINAS.                    *
*******************************************************************

*******************************************************************
*                    LIST OF VARIABLES                            *
*                                                                 *
*   WJET: VELOCITY OF ENGINE EXHAUST (METERS/SEC)                 *
*   MJET: MASS FLOW RATE OF GAS (KG/SECOND/SQ METER)              *
*   TJET: JET EXHAUST GAS TEMPERATURE (DEGREES KELVIN)            *
*   PJET: EXHAUST PRESSURE OF JET ENGINE (NEWTONS/SQ METER)       *
*   RHOJET: DENSITY OF THE GAS (KG/CUBIC METER)                   *
*   HJET: ENTHALPY (JOULES/KG OR NEWTON*METERS/KG)                *
*   KEJET: KINETIC ENERGY (JOULES OR NEWTON-METERS)               *
*   GASCON: GAS CONSTANT (JOULES/(KG-DEG KELVIN))                 *
*   TAMB: AMBIENT AIR TEMPERATURE (DEGREES KELVIN)                *
*   HAMB: AMBIENT ENTHALPY (JOULES/KG)                            *
*   KEINJ: TURBULENT KINETIC ENERGY (JOULES) OF JET               *
*   CSUBP: SP HT @ CONST PRE (JOULES/(KG-DEG KELVIN))             *
*   EPINJ: DISSIPATION RATE OF TURBULENT KE (JOULES) OF JET       *
*   KEINA: TURBULENT KINETIC ENERGY (JOULES) AMBIENT              *
*   EPINA: DISSIPATION RATE OF TURBULENT KE (JOULES) AMBIENT      *
*   P1: PRESSURE (NEWTONS/SQUARE METER)                           *
*   H1: ENTHALPY (JOULES/KG)                                      *
*   U1: VELOCITY IN X-DIRECTION (METERS/SEC)                      *
*   V1: VELOCITY IN Y-DIRECTION (METERS/SEC)                      *
*   W1: VELOCITY IN Z-DIRECTION (METERS/SEC)                      *
*   TMP1: TEMP OF THE FIRST PHASE (DEGREES KELVIN)                *
*   RHO1: DENSITY OF THE FIRST PHASE (KG/CUBIC METER)             *
*   PRESSO: REFERENCE ATMOSPHERIC PRESSURE (NEWTONS/SQ METER)     *
*   TMP1A: GROUND REF TEMP USED IN GRND2 (DEG KELVIN)             *
*   TMP1B: 1/CSUBP USED IN GRND2 EQU (KG-DEG KELVIN/JOULES)       *
*   DRH1DP: DELTA RHO/DELTA PRESSURE W/RESPECT TO H1              *
*   FACT: CORRECTION OR "FUDGE" FACTOR                            *
*   ENUL: LAMINAR KINEMATIC VISCOSITY (METERS SQ/SEC)             *
*   ENUT: TURBULENT KINEMATIC VISCOSITY (METERS SQ/SEC)           *
*******************************************************************

  GROUP 1. RUN TITLE AND OTHER PRELIMINARIES
TEXT(NAS JACKSONVILLE HUSH CHAMBER)
REAL(WJET,MJET,TJET,PJET,RHOJET,HJET,KEJET,GASCON,CSUBP,TAMB,HAMB)
REAL(KEINJ,EPINJ,KEINA,EPINA)

  GROUP 2. TRANSIENCE; TIME-STEP SPECIFICATION (DEFAULT=STEADY)

  GROUP 3. X-DIRECTION GRID SPECIFICATION
NX=10
XFRAC(1)=-1 ; XFRAC(2)=0.31
XFRAC(3)=4  ; XFRAC(4)=0.5475
XFRAC(5)=3  ; XFRAC(6)=2.0
XFRAC(7)=2  ; XFRAC(8)=1.4

  GROUP 4. Y-DIRECTION GRID SPECIFICATION
NY=12
YFRAC(1)=-3  ; YFRAC(2)=0.562
YFRAC(3)=2   ; YFRAC(4)=0.314
YFRAC(5)=3   ; YFRAC(6)=0.562
YFRAC(7)=4   ; YFRAC(8)=0.75

  GROUP 5. Z-DIRECTION GRID SPECIFICATION
NZ=40
ZFRAC(1)=-1  ; ZFRAC(2)=1.0
ZFRAC(3)=1   ; ZFRAC(4)=1.7
ZFRAC(5)=1   ; ZFRAC(6)=2.0
ZFRAC(7)=1   ; ZFRAC(8)=1.7
ZFRAC(9)=2   ; ZFRAC(10)=3.0
ZFRAC(11)=1  ; ZFRAC(12)=1.5
ZFRAC(13)=1  ; ZFRAC(14)=1.0
ZFRAC(15)=1  ; ZFRAC(16)=1.7
ZFRAC(17)=2  ; ZFRAC(18)=1.0
ZFRAC(19)=1  ; ZFRAC(20)=1.7
ZFRAC(21)=2  ; ZFRAC(22)=1.0
ZFRAC(23)=3  ; ZFRAC(24)=0.566666
ZFRAC(25)=2  ; ZFRAC(26)=0.35
ZFRAC(27)=7  ; ZFRAC(28)=3.00
ZFRAC(29)=1  ; ZFRAC(30)=2.0
ZFRAC(31)=4  ; ZFRAC(32)=0.75
ZFRAC(33)=4  ; ZFRAC(34)=0.575
ZFRAC(35)=4  ; ZFRAC(36)=0.5
ZFRAC(37)=1  ; ZFRAC(38)=3.0

  GROUP 6. BODY-FITTED COORDINATES OR GRID DISTORTION

  GROUP 7. VARIABLES STORED, SOLVED & NAMED
SOLVE(P1,H1,U1,V1,W1)
SOLUTN(P1,Y,Y,Y,N,N,N)
STORE(TMP1,RHO1,ENUT)

  GROUP 8. TERMS (IN DIFFERENTIAL EQUATIONS) & DEVICES

  GROUP 9. PROPERTIES OF THE MEDIUM
TAMB=295.
TJET=700
PJET=0.
MJET=197.72
PRESS0=101325.
RHO1A=0.
GASCON=286.
RHO1B=1./GASCON
RHOJET=((PRESS0+PJET)*RHO1B)/TJET
WJET=MJET/RHOJET
TMP1A=TINY
   *** TMP1B IS EQUAL TO 1. DIVIDED BY C-SUB-P; USED IN TMP1=GRND5
CSUBP=1004.
HAMB=TAMB*CSUBP
```

```
TMP1B=1./CSUBP
HJET=CSUBP*TJET
  ** THE NEXT 2 STATEMENTS INVOKE COMPRESSIBLE FLOW IN GREX1
TMP1=GRND2
RHO1=GRND5
DRH1DP=GRND5
ENUT=GRND
    KEINJ=0.5*(0.005*WJET)**2 ; EPINJ=0.09*KEINJ**1.5/(0.05*0.5)
    KEINA=0.5*(.005*1.0)**2 ; EPINA=0.09*KEINA**1.5/(0.1)

  GROUP 10. INTER-PHASE-TRANSFER PROCESSES AND PROPERTIES

  GROUP 11. INITIALIZATION OF VARIABLE OR POROSITY FIELDS
FIINIT(H1)=HAMB
FIINIT(TMP1)=TAMB ; FIINIT(DEN1)=1.0
    FIINIT(KE)=KEINA ; FIINIT(EP)=EPINA
FIINIT(P1)=0.0
FIINIT(W1)=0.0
FIINIT(V1)=0.0
FIINIT(U1)=0.0
    PATCH(WINIT,INIVAL,1,5,1,8,15,30,1,1)
    INIT(WINIT,W1,0.0,0.2*WJET)
    INIT(WINIT,H1,0.0,CSUBP*0.2*TJET)
    INIT(WINIT,KE,0.0,KEINJ*0.2)
    INIT(WINIT,EP,0.0,EPINJ*0.2)
  *** SEE GROUP 13 FOR POROSITY FIELDS

  GROUP 12. CONVECTION AND DIFFUSION ADJUSTMENTS

  GROUP 13. BOUNDARY CONDITIONS AND SPECIAL SOURCES
   **DEFINE SOURCES AND SINKS FOR JET ENGINE**
CONPOR(0.0,CELL,1,1,4,5,12,14)
PATCH(JETIN,HIGH,1,1,4,5,11,11,1,1)
COVAL(JETIN,P1,FIXFLU,-MJET)
COVAL(JETIN,H1,ONLYMS,SAME)
PATCH(JETOUT,LOW,1,1,4,5,15,15,1,1)
COVAL(JETOUT,P1,FIXFLU,MJET)
COVAL(JETOUT,H1,ONLYMS,HJET)
COVAL(JETOUT,W1,ONLYMS,WJET)
    COVAL(JETOUT,KE,ONLYMS,KEINJ)
    COVAL(JETOUT,EP,ONLYMS,EPINJ)

   **EAST BOUNDARY TO ATMOSPHERE**
PATCH(OUTSIDE,EAST,10,10,1,12,1,40,1,1)
COVAL(OUTSIDE,P1,0.1,0.0)
COVAL(OUTSIDE,H1,FIXVAL,HAMB)

   **TOP OF HUSH HOUSE AND TUBE INCLUDING TUBE LIP**
CONPOR(0.0,NORTH,1,9,12,12,1,19)
CONPOR(0.0,NORTH,1,5,-8,-8,18,27)
CONPOR(0.0,NORTH,1,5,-2,-2,35,35)
CONPOR(0.0,NORTH,1,5,-4,-4,36,36)
CONPOR(0.0,NORTH,1,5,-5,-5,37,37)
CONPOR(0.0,NORTH,1,5,-6,-6,38,38)
CONPOR(0.0,NORTH,1,5,-7,-7,39,39)
```

```
   **TOP OF MODEL TO ATMOSPHERE**
PATCH(TOPOUT,NORTH,1,10,12,12,20,40,1,1)
COVAL(TOPOUT,P1,0.1,0.0)
COVAL(TOPOUT,H1,ONLYMS,HAMB)
PATCH(TOPP,NORTH,10,10,12,12,1,19,1,1)
COVAL(TOPP,P1,0.1,0.0)
COVAL(TOPP,H1,ONLYMS,HAMB)

   **FLOOR OF HUSH HOUSE, TUBE AND GROUND**
CONPOR(0.0,SOUTH,1,10,1,-1,1,40)

   **FORE AND AFT BULKHEADS IN HUSH HOUSE AND TUBE**
CONPOR(0.0,LOW,1,9,1,12,-1,-1)
CONPOR(0.0,LOW,6,9,1,12,-20,-20)
CONPOR(0.0,LOW,1,5,9,12,-20,-20)
CONPOR(0.0,LOW,1,5,1,2,-35,-35)
CONPOR(0.0,LOW,1,5,3,4,-36,-36)
CONPOR(0.0,LOW,1,5,5,5,-37,-37)
CONPOR(0.0,LOW,1,5,6,6,-38,-38)
CONPOR(0.0,LOW,1,5,7,7,-39,-39)
CONPOR(0.0,HIGH,1,5,8,8,-39,-39)

   **VERY FRONT MODEL STRIP TO ATMOSPHERE**
PATCH(FRONT,LOW,10,10,1,12,1,1,1,1)
COVAL(FRONT,P1,0.1,0.0)
COVAL(FRONT,H1,ONLYMS,HAMB)

   **THE VERY END OF OUR MODEL TO ATMOSPHERE**
PATCH(ENDEND,HIGH,1,10,1,12,40,40,1,1)
COVAL(ENDEND,P1,0.1,0.0)
COVAL(ENDEND,H1,ONLYMS,HAMB)

   **OUTSIDE EAST WALL IN HUSH HOUSE**
CONPOR(0.0,EAST,-9,-9,9,12,1,19)
CONPOR(0.0,EAST,-9,-9,1,8,1,1)
CONPOR(0.0,EAST,-9,-9,1,8,3,3)
CONPOR(0.0,EAST,-9,-9,1,8,5,8)
CONPOR(0.0,EAST,-9,-9,1,8,10,11)
CONPOR(0.0,EAST,-9,-9,1,8,13,14)
CONPOR(0.0,EAST,-9,-9,1,8,18,19)

   **OUTSIDE OF TUBE PLUS TUBE LIP IN HUSH HOUSE**
CONPOR(0.0,EAST,-5,-5,1,8,18,39)

  GROUP 14. DOWNSTREAM PRESSURE FOR PARAB=.TRUE.

  GROUP 15. TERMINATION OF SWEEPS
FSWEEP=1 ; LSWEEP=90

  GROUP 16. TERMINATION OF ITERATIONS

LITER(P1)=40
  GROUP 17. UNDER-RELAXATION DEVICES
REAL(DELT,FACT)
DELT=50.0/(NZ*0.2*WJET)
```

```
    FACT=10.
FACT=1.00
    FACT=0.75
    FACT=3.5
    FACT=5.
    FACT=0.50
    FACT=0.1
RELAX(P1,LINRLX,0.3)
RELAX(U1,FALSDT,FACT*DELT)
RELAX(V1,FALSDT,FACT*DELT)
RELAX(W1,FALSDT,FACT*DELT)
RELAX(H1,FALSDT,FACT*DELT)
    RELAX(KE,FALSDT,FACT*DELT)
    RELAX(EP,FALSDT,FACT*DELT)

  GROUP 18. LIMITS ON VARIABLES OR INCREMENTS TO THEM
VARMIN(U1)=-300.
VARMAX(U1)=1000.
VARMIN(V1)=-300.
VARMAX(V1)=1000.
VARMIN(W1)=-100.
VARMAX(W1)=1500.
VARMIN(TMP1)=250
VARMAX(TMP1)=TJET
VARMIN(H1)=1000.
VARMAX(H1)=CSUBP*TJET
VARMIN(P1)=-3.5E+05
VARMAX(P1)= 3.5E+05
VARMIN(RHO1)=.05
VARMAX(RHO1)=5.
   VARMIN(KE)=1.E-10
   VARMAX(KE)=1.E10
   VARMIN(EP)=1.E-08
   VARMIN(VIST)=1.E-20
   VARMAX(EP)=1.3*(KEJET**1.5)

  GROUP 19. DATA COMMUNICATED BY SATELLITE TO GROUND
USEGRD=T

  GROUP 20. PRELIMINARY PRINT-OUT

  GROUP 21. PRINT-OUT OF VARIABLES

  GROUP 22. SPOT-VALUE PRINT-OUT
    **MONITOR THE OUTPUT AT DESIGNATED POINTS**
IXMON=1 ; IYMON=4 ; IZMON=16
TSTSWP=1 ; LUPR3=6
ABSIZ=1.0 ; ORSIZ=1.0

  GROUP 23. FIELD PRINT-OUT AND PLOT CONTROL
NUMCLS=10*NXPRIN
ITABL=3 ; NPLT=1 ; NZPRIN=1
IPLTL=LSWEEP
    NPRINT=3
  GROUP 24. DUMPS FOR RESTARTS
SAVE=T
    RESTRT(P1,U1,V1,W1)
RESTRT(ALL)
STOP
//
```

APPENDIX B. PROGRAM FOR COPYING MVS DATA SETS

A. COPYTAPE

```
//RATNER JOB (2529,9999),'XHUSH',CLASS=A
//  EXEC    PGM=IEBGENER
//SYSPRINT  DD  SYSOUT=A
//SYSIN     DD  DUMMY
//SYSUT1    DD  DSN=MSS.S1541.PHOENICS.CONV7,DISP=SHR
//SYSUT2    DD  DSN=MSS.S1541.PHOENICS.DF09G,DISP=(SHR)
//
```

APPENDIX C. "GROUND" FILE (GROUP 9)

Section 5 shows the code required to evaluate "ENUT" (eqation (3.10)).

```
C******************************************************************
C
C--- GROUP 9. Properties of the medium (or media)
C
C   The sections in this group are arranged sequentially in their
C   order of calling from EARTH. Thus, as can be seen from below,
C   the temperature sections (10 and 11) precede the density
C   sections (1 and 3); so, density formulae can refer to
C   temperature stores already set.
    9 GO TO (91,92,93,94,95,96,97,98,99,900,901,902,903),ISC
C******************************************************************
  900 CONTINUE
C   * ------------------- SECTION 10 ---------------------------
C    For TMP1.LE.GRND--------- phase-1 temperature Index AUX(TEMP1)
      RETURN
  901 CONTINUE
C   * ------------------- SECTION 11 ---------------------------
C    For TMP2.LE.GRND--------- phase-2 temperature Index AUX(TEMP2)
      RETURN
  902 CONTINUE
C   * ------------------- SECTION 12 ---------------------------
C    For EL1.LE.GRND--------- phase-1 length scale Index AUX(LEN1)
      RETURN
  903 CONTINUE
C   * ------------------- SECTION 13 ---------------------------
C    For EL2.LE.GRND--------- phase-2 length scale Index AUX(LEN2)
      RETURN
   91 CONTINUE
C   * ------------------- SECTION  1 ---------------------------
C    For RHO1.LE.GRND--- density for phase 1 Index AUX(DEN1).
  965 CONTINUE
      RETURN
   92 CONTINUE
C   * ------------------- SECTION  2 ---------------------------
C    For DRH1DP.LE.GRND--- D(LN(DEN))/DP for phase 1 (D1DP).
      RETURN
   93 CONTINUE
C   * ------------------- SECTION  3 ---------------------------
C    For RHO2.LE.GRND--- density for phase 2 Index AUX(DEN2).
      RETURN
   94 CONTINUE
C   * ------------------- SECTION  4 ---------------------------
C    For DRH2DP.LE.GRND--- D(LN(DEN))/DP for phase 2 (D2DP).
      RETURN
   95 CONTINUE
C   * ------------------- SECTION  5 ---------------------------
C    For ENUT.LE.GRND--- reference turbulent kinematic viscosity.
      CALL FN5(AUX(VIST),AUX(TEMP1),4.886,5.432E-2,-2.426E-5,7.931E-9,
     1-1.104E-12)
      CALL FN25(AUX(VIST),1.0E-6)
      CALL FN27(AUX(VIST),AUX(DEN1))
      CALL FN25(AUX(VIST),1000.0)
      RETURN
   96 CONTINUE
C   * ------------------- SECTION  6 ---------------------------
C    For ENUL.LE.GRND--- reference laminar kinematic viscosity.
      RETURN
   97 CONTINUE
C   * ------------------- SECTION  7 ---------------------------
C    For PRNDTL( ).LE.GRND--- laminar PRANDTL nos., or diffusivity.
      RETURN
   98 CONTINUE
C   * ------------------- SECTION  8 ---------------------------
C    For PHINT( ).LE.GRND--- interface value of first phase(FII1).
      RETURN
   99 CONTINUE
C   * ------------------- SECTION  9 ---------------------------
C    For PHINT( ).LE.GRND--- interface value of second phase(FII2)
      RETURN
C*********************************************************************
```

APPENDIX D. PROGRAMS REQUIRED FOR IMPLEMENTING GROUND

A. COPYGRD

```
//COPYGRD JOB (2529,9999),'COPYTMVS',CLASS=A
// EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSIN DD DUMMY
//SYSUT2 DD UNIT=SYSDA,
//       DSN=MSS.S1541.PHOENICS.SRC(GROUND),DISP=SHR
//SYSUT1 DD *
      PROGRAM MAIN
C THIS IS THE MAIN PROGRAM OF EARTH
C FILE NAME GROUND.FTN-------------------------------16 July 1986
C
C   (C) COPYRIGHT 1984, LAST REVISION 1986.
C   CONCENTRATION HEAT AND MOMENTUM LTD. ALL RIGHTS RESERVED.
C   This subroutine and the remainder of the PHOENICS code are
C   proprietary software owned by Concentration Heat and Momentum
C   Limited, 40 High Street, Wimbledon, London SW19 5AU, England.
C
C
C     PROGRAM MAIN
C
C 1   The following two COMMON's, which appear identically in the
C     satellite MAIN program, allow up to 25 dependent variables to
C     be solved for (or their storage spaces to be occupied by
C     other variables, such as density). If a larger number is
C     required, the 25's should be replaced, in the next 8 lines,
C     by the required larger number; and the 100 in COMMON/F01/
C     should be replaced by 4 times the required number. Numbers
C     less than 25 are not permitted.
C
      COMMON/LGE1/L1(25)/LGE2/L2(25)/LGE3/L3(25)/LGE4/L4(25)
     1/LDB1/L5(25)/IDA1/I1(25)/IDA2/I2(25)/IDA3/I3(25)/IDA4/I4(25)
     1/IDA5/I5(25)/IDA6/I6(25)/GI1/I7(25)/GI2/I8(25)/HDA1/IH1(25)
     1/GH1/IH2(25)/RDA1/R1(25)/RDA2/R2(25)/RDA3/R3(25)/RDA4/R4(25)
     1/RDA5/R5(25)/RDA6/R6(25)/RDA7/R7(25)/RDA8/R8(25)/RDA9/R9(25)
     1/RDA10/R10(25)/RDA11/R11(25)
     1/GR1/R12(25)/GR2/R13(25)/GR3/R14(25)/GR4/R15(25)
     1/IPIP1/IP1(25)/HPIP2/IHP2(25)/RPIP1/RVAL(25)/LPIP1/LVAL(25)
     1/IFPL/IPLO(25)/RFPL1/ORPRIN(25)/RFPL2/ORMAX(25)
     1/RFPL3/ORMIN(25)/RFPL4/CELAV(25)
      LOGICAL L1,L2,L3,L4,L5,DBGFIL,LVAL
      CHARACTER*4 IH1,IH2,IHP2,NSDA
C
      COMMON/F01/I9(100)
      COMMON/DISC/DBGFIL
      EXTERNAL WAYOUT
C
```

```
C 2   Set dimensions of data-for-GROUND arrays here. WARNING: the
C     corresponding arrays in the MAIN program of the satellite
C     (see SATLIT) must have the same dimensions.
      COMMON/LGRND/LG(20)/IGRND/IG(20)/RGRND/RG(100)/CGRND/CG(10)
      LOGICAL LG
      CHARACTER*4 CG
C
C 3   Set dimensions of data-for-GREX1 arrays here. WARNING: the
C     corresponding arrays in the MAIN program of the satellite
C     (see SATLIT) must have the same dimensions.
      COMMON/LSG/LSGD(20)/ISG/ISGD(20)/RSG/RSGD(100)/CSG/CSGD(10)
      LOGICAL LSGD
      CHARACTER*4 CSGD
C
C 4   Set dimension of patch-name array here. WARNING: the array
C     NAMPAT in the MAIN program of the satellite must have the
C     SAME DIMENSION.
      COMMON/NPAT/NAMPAT(500)
      CHARACTER*8 NAMPAT
C
C     Declare local CHARACTER variables.
      CHARACTER NDUM4*4,NDUM6*6,NDUM15*15
C
C 5   The numbers in the next two statements (which must be ident-
C     ical) indicate how much computer memory is to be set aside
C     for storing the main and auxiliary variables. The user may
C     alter them if he wishes, to accord with the number of
C     grid nodes and dependent variables he is concerned with.
      COMMON F(500000)
      NFDIM=500000
C
C 6   Logical-unit numbers and file names, not to be changed.
      DBGFIL=.FALSE.
      CALL DSCEAR(14,LUPR3,'  ',15,NDUM15,-11,16)
      CALL DSCEAR(6,LUDUM,'  ',4,NDUM4,9,33)
      CALL DSCEAR(-10,LUSDA,'  ',4,NSDA,0,0)
      CALL DSCEAR(-14,LUPR1,'  ',15,NDUM15,0,0)
      CALL DSCEAR(21,LUDST,'  ',4,NDUM4,9,33)
C
C     User may here change message transmitted to logical unit
C     LUPR3
      CALL WRIT40('GROUND STATION IS GROUND.FTN 11 JULY 86 ')
      CALL MAIN1(NFDIM,LUPR1,LUPR3,LUSDA,NSDA)
      CALL WAYOUT(0)
      STOP
      END
C***********************************************************************
      SUBROUTINE GROSTA
C (C) COPYRIGHT 1984, LAST REVISION 1986.
C  CONCENTRATION HEAT AND MOMENTUM LTD. ALL RIGHTS RESERVED.
      INCLUDE (SATEAR)
      INCLUDE (GRDLOC)
      INCLUDE (GRDEAR)
C.... This subroutine directs control to the GROUNDs selected by
C     the satellite settings of USEGRX, NAMGRD & USEGRD.
C           Subroutine GREX1 contains much standard material, eg.
```

```
C     options for fluid properties, several turbulence models,
C     wall functions, etc.
C
          IF(USEGRX) CALL GREX1
C
C.... ESTER is for electrolytic-smelter modelling of the Hall-cell
C     and Soderberg types used in the reduction of aluminium.
C
          IF(NAMGRD.EQ.'ESTR') CALL ESTRGR
C
C.... SCRS contains the simple-chemical-reaction-model of
C     combustion, the theoretical basis of which is found in the
C     book "Combustion & Mass Transfer" by D B Spalding (1979)
C     This ground also contains geometrical features of a
C     simplified can combustor.
C
          IF(NAMGRD.EQ.'SCRS') CALL SCRSGR
C
C.... A more advanced model of a combustor is given in COMBGR.
C
          IF(NAMGRD.EQ.'COMB') CALL COMBGR
C
C.... WJETGR shows how to represent non-isotropic effects in the
C     turbulence of a wall jet.
C
          IF(NAMGRD.EQ.'WJET') CALL WJETGR
C
C.... TRACGR contains software for tracking fluid interfaces by
C     means of a set of imaginary particles which follow the motion
C
          IF(NAMGRD.EQ.'TRAC') CALL TRACGR
C
C.... PARTGR is used to solve for the motion of particles slipping
C     relative to the host fluid. A spectrum of particle sizes can
C     can be represented. Each particle is characterized by a size,
C     an interphase friction coefficient, an evaporation rate & a
C     temperature.
C
          IF(NAMGRD.EQ.'PART') CALL PARTGR
C
C.... RADIGR provides the coding sequences required to activate
C     the so-called six-flux radiation model.
C
          IF(NAMGRD.EQ.'RADI') CALL RADIGR
C
C.... GAUSGR provides the Gauss-Seidel solver as an alternative
C     to the whole-field linear equation solver provided in EARTH.
C
          IF(NAMGRD.EQ.'GAUS') CALL GAUSGR
C
C.... NOZLGR provides initial conditions & special print out for
C     a convergent-divergent nozzle case for which body-fitted
C     coordinates are used.
C
          IF(NAMGRD.EQ.'NOZL') CALL NOZLGR
C
```

```
C.... AEROGR provides inlet boundary conditions & initial conditions
C     for a one-half C grid for an aerofoil.
C
          IF(NAMGRD.EQ.'AERO') CALL AEROGR
C
C.... POLRGR specifies uniform flow boundary conditions into
C     a polar domain of 360 degree extent.
C
          IF(NAMGRD.EQ.'POLR') CALL POLRGR
C
C.... BTSTGR contains the sequenses used in conjunction with
C     the BFC test battery.
C
          IF(NAMGRD.EQ.'BTST') CALL BTSTGR
C
C.... TESTGR contains test battery sequences used in conjunction
C     with the test-battery SATLIT subroutine, TESTST.
C
          IF(NAMGRD.EQ.'TEST') CALL TESTGR
C
C.... SPECGR is a generic "special" GROUND the name of which can
C     be used by anyone for their own purposes.
C
          IF(NAMGRD.EQ.'SPEC') CALL SPECGR
C
C.... The model ground is for the insertion of new user sequences.
C
          IF(USEGRD) CALL GROUND
C
C.... The data echo is now called at the preliminary print stage.
C
          IF(IGR.NE.20) RETURN
          IF(.NOT.ECHO) GO TO 20
      CALL DATPRN(Y,Y,Y,Y,  Y,Y,Y,Y,  Y,Y,Y,N,  Y,Y,Y,Y,
     1          Y,Y,Y,Y,  Y,Y,Y,Y)
      RETURN
   20 CALL DATPRN(Y,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N)
      RETURN
      END
C***************************************************************
      SUBROUTINE GROUND
C (C) COPYRIGHT 1984, LAST REVISION 1986.
C  CONCENTRATION HEAT AND MOMENTUM LTD. ALL RIGHTS RESERVED.
      INCLUDE (SATEAR)
      INCLUDE (GRDLOC)
      INCLUDE (GRDEAR)
      INTEGER HIGH,OLD,AUX,SOUTH,NORTH,EAST,WEST
      LOGICAL STORE,SOLVE,PRINT
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION STARTS:
C
C 1   Set dimensions of data-for-GROUND arrays here. WARNING: the
C     corresponding arrays in the MAIN program of the satellite
C     and EARTH must have the same dimensions.
      COMMON/LGRND/LG(20)/IGRND/IG(20)/RGRND/RG(100)/CGRND/CG(10)
      LOGICAL LG
      CHARACTER*4 CG
C
C 2   User dimensions own arrays here, for example:
C     DIMENSION UUH(10,10),UUC(10,10),UUX(10,10),UUZ(10)
      PARAMETER(MY=20,MX=1)
      DIMENSION GV1(MY,MX),GW1(MY,MX),GTMP1(MY,MX),GRHO1(MY,MX)
      DIMENSION GH1(MY,MX),GENUL(MY,MX),GMACH(MY,MX),GHC(MY,MX)
      DIMENSION GST(MY,MX),GCF(MY,MX),GQ(MY,MX),GTAU(MY,MX)
      COMMON CP,GAMA,RAIR,PRL,RFAC
C
C 3   User places his data statements here, for example:
C     DATA NXDIM,NYDIM/10,10/
C
C 4   Index functions for GROUND-EARTH variable references.
      LOW(I)=NPHI+I
      HIGH(I)=2*NPHI+I
      OLD(I)=3*NPHI+I
      IN(I)=4*NPHI+I
      STORE(I)=MOD(ISLN(I),2).EQ.0
      SOLVE(I)=MOD(ISLN(I),3).EQ.0
      PRINT(I)=MOD(IPRN(I),2).EQ.0
      SOUTH(I)=-(KF(I)-1)
      NORTH(I)=-(KF(I)+1)
      EAST(I)=-(KF(I)+NY)
      WEST(I)=-(KF(I)-NY)
C
C 5   Insert own coding below as desired, guided by GREX1 examples.
C     Note that the satellite-to-GREX1 special data in the labelled
C     COMMONs /RSG/, /ISG/, /LSG/ and /CSG/ can be included and
C     used below but the user must check GREX1 for any conflicting
C     uses. The same comment applies to the EARTH-spare working
C     arrays EASP1, EASP2,....EASP10. If the call to GREX1 has been
C     deactivated then they can all be used without reservation.
C
      IXL=IABS(IXL)
          IF(IGR.EQ.13) GO TO 13
          IF(IGR.EQ.19) GO TO 19
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
     122,23,24),IGR
C*****************************************************************
C
C--- GROUP 1. Run title and other preliminaries
C
    1 GO TO (1001,1002),ISC
 1001 CONTINUE
      RETURN
 1002 CONTINUE
      RETURN
C*****************************************************************
C
C--- GROUP 2. Transience; time-step specification
C
    2 CONTINUE
      RETURN
C*****************************************************************
C
```

```
C--- GROUP 3. X-direction grid specification
C
    3 CONTINUE
      RETURN
C*******************************************************************
C
C--- GROUP 4. Y-direction grid specification
C
    4 CONTINUE
      RETURN
C*******************************************************************
C
C--- GROUP 5. Z-direction grid specification
C
    5 CONTINUE
      RETURN
C*******************************************************************
C
C--- GROUP 6. Body-fitted coordinates or grid distortion
C
    6 CONTINUE
      RETURN
C*******************************************************************
C
C--- GROUP 7. Variables stored, solved & named
    7 CONTINUE
      RETURN
C*******************************************************************
C
C--- GROUP 8. Terms (in differential equations) & devices
C
    8 GO TO (81,82,83,84,85,86,87,88,89,810,811,812,813,814,815)
     1,ISC
   81 CONTINUE
C   * ------------------ SECTION  1 ---------------------------
C    For U1AD.LE.GRND--- phase 1 additional velocity (VELAD).
      RETURN
   82 CONTINUE
C   * ------------------ SECTION  2 ---------------------------
C    For U2AD.LE.GRND--- phase 2 additional velocity (VELAD).
      RETURN
   83 CONTINUE
C   * ------------------ SECTION  3 ---------------------------
C    For V1AD.LE.GRND--- phase 1 additional velocity (VELAD).
      RETURN
   84 CONTINUE
C   * ------------------ SECTION  4 ---------------------------
C    For V2AD.LE.GRND--- phase 2 additional velocity (VELAD).
      RETURN
   85 CONTINUE
C   * ------------------ SECTION  5 ---------------------------
C    For W1AD.LE.GRND--- phase 1 additional velocity (VELAD).
      RETURN
   86 CONTINUE
C   * ------------------ SECTION  6 ---------------------------
C    For W2AD.LE.GRND--- phase 2 additional velocity (VELAD).
```

```
      RETURN
   87 CONTINUE
C   * ------------------- SECTION 7 ---- VOLUMETRIC SOURCE FOR GALA
      RETURN
   88 CONTINUE
C   * ------------------- SECTION 8 --- CONVECTION FLUXES
      RETURN
   89 CONTINUE
C   * ------------------- SECTION 9 --- DIFFUSION COEFFICIENTS
      RETURN
  810 CONTINUE
C   * ------------------- SECTION 10 --- CONVECTION NEIGHBOURS
      RETURN
  811 CONTINUE
C   * ------------------- SECTION 11 --- DIFFUSION NEIGHBOURS
      RETURN
  812 CONTINUE
C   * ------------------- SECTION 12 --- LINEARISED SOURCES
      RETURN
  813 CONTINUE
C   * ------------------- SECTION 13 --- CORRECTION COEFFICIENTS
      RETURN
  814 CONTINUE
C   * ------------------- SECTION 14 --- USER'S SOLVER
      RETURN
  815 CONTINUE
C   * ------------------- SECTION 15 --- CHANGE SOLUTION
      RETURN
C   * Make all other group-8 changes in group 19.
C**************************************************************************
C
C--- GROUP 9. Properties of the medium (or media)
C
C   The sections in this group are arranged sequentially in their
C   order of calling from EARTH. Thus, as can be seen from below,
C   the temperature sections (10 and 11) precede the density
C   sections (1 and 3); so, density formulae can refer to
C   temperature stores already set.
    9 GO TO (91,92,93,94,95,96,97,98,99,900,901,902,903),ISC
C**************************************************************************
  900 CONTINUE
C   * ------------------- SECTION 10 --------------------------
C    For TMP1.LE.GRND--------- phase-1 temperature Index AUX(TEMP1)
      RETURN
  901 CONTINUE
C   * ------------------- SECTION 11 --------------------------
C    For TMP2.LE.GRND--------- phase-2 temperature Index AUX(TEMP2)
      RETURN
  902 CONTINUE
C   * ------------------- SECTION 12 --------------------------
C    For EL1.LE.GRND--------- phase-1 length scale Index AUX(LEN1)
      RETURN
  903 CONTINUE
C   * ------------------- SECTION 13 --------------------------
C    For EL2.LE.GRND--------- phase-2 length scale Index AUX(LEN2)
      RETURN
   91 CONTINUE
C   * ------------------- SECTION  1 ---------------------------
C    For RHO1.LE.GRND--- density for phase 1 Index AUX(DEN1).
  965 CONTINUE
      RETURN
   92 CONTINUE
C   * ------------------- SECTION  2 ---------------------------
C    For DRH1DP.LE.GRND--- D(LN(DEN))/DP for phase 1 (D1DP).
      RETURN
   93 CONTINUE
C   * ------------------- SECTION  3 ---------------------------
C    For RHO2.LE.GRND--- density for phase 2 Index AUX(DEN2).
      RETURN
   94 CONTINUE
C   * ------------------- SECTION  4 ---------------------------
C    For DRH2DP.LE.GRND--- D(LN(DEN))/DP for phase 2 (D2DP).
      RETURN
   95 CONTINUE
C   * ------------------- SECTION  5 ---------------------------
C    For ENUT.LE.GRND--- reference turbulent kinematic viscosity.
      CALL FN5(AUX(VIST),AUX(TEMP1),4.886,5.432E-2,-2.426E-5,7.931E-9,
     1-1.104E-12)
      CALL FN25(AUX(VIST),1.0E-6)
      CALL FN27(AUX(VIST),AUX(DEN1))
      CALL FN25(AUX(VIST),20000.0)
      RETURN
   96 CONTINUE
C   * ------------------- SECTION  6 ---------------------------
C    For ENUL.LE.GRND--- reference laminar kinematic viscosity.
      RETURN
   97 CONTINUE
C   * ------------------- SECTION  7 ---------------------------
C    For PRNDTL( ).LE.GRND--- laminar PRANDTL nos., or diffusivity.
      RETURN
   98 CONTINUE
C   * ------------------- SECTION  8 ---------------------------
C    For PHINT( ).LE.GRND--- interface value of first phase(FII1).
      RETURN
   99 CONTINUE
C   * ------------------- SECTION  9 ---------------------------
C    For PHINT( ).LE.GRND--- interface value of second phase(FII2)
      RETURN
C******************************************************************
C
C--- GROUP 10. Inter-phase-transfer processes and properties
C
   10 GO TO (101,102,103,104),ISC
  101 CONTINUE
C   * ------------------- SECTION  1 ---------------------------
C    For CFIPS.LE.GRND--- inter-phase friction coeff. AUX(INTFRC).
      RETURN
  102 CONTINUE
C   * ------------------- SECTION  2 ---------------------------
C    For CMDOT.EQ.GRND- inter-phase mass transfer Index AUX(INTMDT)
      RETURN
  103 CONTINUE
C   * ------------------- SECTION  3 --------------------------
C    For CINT( ).EQ.GRND--- phase1-to-interface transfer
C                                          coefficients (COI1)
      RETURN
  104 CONTINUE
C   * ------------------- SECTION  4 --------------------------
C    For CINT( ).EQ.GRND--- phase2-to-interface transfer
C                                          coefficients (COI2)
      RETURN
C**********************************************************************
C
C--- GROUP 11. Initialization of variable or porosity fields
C
   11 CONTINUE
      RETURN
C**********************************************************************
C
C--- GROUP 12. Convection and diffusion adjustments
C
   12 CONTINUE
      RETURN
C**********************************************************************
C
C--- GROUP 13. Boundary conditions and special sources
C
   13 CONTINUE
      GO TO (130,131,132,133,134,135,136,137,138,139,1310,
     11311,1312,1313,1314,1315,1316,1317,1318,1319,1320,1321),ISC
  130 CONTINUE
C------------------- SECTION  1 ------------- coefficient = GRND
  131 CONTINUE
C------------------- SECTION  2 ------------- coefficient = GRND1
      RETURN
  132 CONTINUE
C------------------- SECTION  3 ------------- coefficient = GRND2
      RETURN
  133 CONTINUE
C------------------- SECTION  4 ------------- coefficient = GRND3
      RETURN
  134 CONTINUE
C------------------- SECTION  5 ------------- coefficient = GRND4
      RETURN
  135 CONTINUE
C------------------- SECTION  6 ------------- coefficient = GRND5
      RETURN
  136 CONTINUE
C------------------- SECTION  7 ------------- coefficient = GRND6
      RETURN
  137 CONTINUE
C------------------- SECTION  8 ------------- coefficient = GRND7
      RETURN
  138 CONTINUE
C------------------- SECTION  9 ------------- coefficient = GRND8
      RETURN
  139 CONTINUE
C------------------- SECTION 10 ------------- coefficient = GRND9
      RETURN
 1310 CONTINUE
C------------------- SECTION 11 ------------- coefficient = GRND10
      RETURN
 1311 CONTINUE
C------------------- SECTION 12 -------------------- value = GRND
 1351 CONTINUE
      RETURN
 1312 CONTINUE
C------------------- SECTION 13 -------------------- value = GRND1
      RETURN
 1313 CONTINUE
C------------------- SECTION 14 -------------------- value = GRND2
      RETURN
 1314 CONTINUE
C------------------- SECTION 15 -------------------- value = GRND3
      RETURN
 1315 CONTINUE
C------------------- SECTION 16 -------------------- value = GRND4
      RETURN
 1316 CONTINUE
C------------------- SECTION 17 -------------------- value = GRND5
      RETURN
 1317 CONTINUE
C------------------- SECTION 18 -------------------- value = GRND6
      RETURN
 1318 CONTINUE
C------------------- SECTION 19 -------------------- value = GRND7
      RETURN
 1319 CONTINUE
C------------------- SECTION 20 -------------------- value = GRND8
      RETURN
 1320 CONTINUE
C------------------- SECTION 21 -------------------- value = GRND9
      RETURN
 1321 CONTINUE
C------------------- SECTION 22 -------------------- value = GRND10
      RETURN
C****************************************************************
C
C--- GROUP 14. Downstream pressure for PARAB=.TRUE.
C
   14 CONTINUE
      RETURN
C****************************************************************
C
C--- GROUP 15. Termination of sweeps
C
   15 CONTINUE
C   * Make changes for this group only in group 19.
      RETURN
C****************************************************************
C
```

```
C--- GROUP 16. Termination of iterations
C
   16 CONTINUE
C   * Make changes for this group only in group 19.
      RETURN
C***************************************************************************
C
C--- GROUP 17. Under-relaxation devices
C
   17 CONTINUE
C   * Make changes for this group only in group 19.
      RETURN
C***************************************************************************
C
C--- GROUP 18. Limits on variables or increments to them
C
   18 CONTINUE
C   * Make changes for this group only in group 19.
      RETURN
C***************************************************************************
C
C--- GROUP 19. Special calls to GROUND from EARTH
C
   19 GO TO (191,192,193,194,195,196,197,198),ISC
  191 CONTINUE
C   * ------------------- SECTION 1 ---- START OF TIME STEP.
      RETURN
  192 CONTINUE
C   * ------------------- SECTION 2 ---- START OF SWEEP.
      RETURN
  193 CONTINUE
C   * ------------------- SECTION 3 ---- START OF IZ SLAB.
      RETURN
  194 CONTINUE
C   * ------------------- SECTION 4 ---- START OF ITERATION.
      RETURN
  195 CONTINUE
C   * ------------------- SECTION 5 ---- FINISH OF ITERATION.
      RETURN
  196 CONTINUE
C   * ------------------- SECTION 6 ---- FINISH OF IZ SLAB.
C     OPEN (UNIT = 10, FILE = 'DATA')
C     CALL GETYX(V1,GV1,MY,MX)
C     CALL GETYX(W1,GW1,MY,MX)
C     CALL GETYX(AUX(TEMP1),GTMP1,MY,MX)
C     CALL GETYX(AUX(DEN1),GRHO1,MY,MX)
C     CALL GETYX(H1,GH1,MY,MX)
C     CALL GETYX(AUX(VISL),GENUL,MY,MX)
C     DO 1000 I=1,MY
C     GSONIC = (GAMA*RAIR*GTMP1(I,1))**.5
C     GVEL = (GV1(I,1)**2 + GW1(I,1)**2)**.5
C     IF((IZ .EQ. 10) .AND. (IY .EQ. 1) .AND.
C    1(ISWEEP .EQ. LSWEEP))THEN
C     WRITE(10,*) 'GV1 =', GV1(1,1)
C     WRITE(10,*) 'GTMP1 =', GTMP1(1,1)
C     WRITE(10,*) 'GW1 =', GW1(1,1)
```

```
C     END IF
C1000 GMACH(I,1) = GVEL/GSONIC
C     CALL SETYX(C1,GMACH,MY,MX)
C     CALL GETONE(AUX(TEMP1),TINF,MY,1)
C     CALL GETONE(C1,MINF,MY,1)
C     CALL GETONE(W1,WINF,MY,1)
C     CALL GETONE(AUX(DEN1),RHOI,MY,1)
C     GTR = TINF*(1 + (RFAC*(GAMA - 1.))*(MINF**2)/2)
C     DO 1010 I=1,MY
C     GQ(I,1)=(GRHO1(I,1)*GENUL(I,1)/.7)*((GH1(I,1)-CP*TWAL)/2.5E-4)
C     GHC(I,1) = GQ(I,1)/(GTR - TWAL)
C     GST(I,1) = GHC(I,1)/(RHOI*WINF*CP)
C     GTAU(I,1) = GRHO1(I,1)*GENUL(I,1)*GW1(I,1)/2.5E-4
C1010 GCF(I,1) = 2*GTAU(I,1)/(RHOI*WINF**2)
C     CALL SETYX(C2,GHC,MY,MX)
C     CALL SETYX(C3,GST,MY,MX)
C     CALL SETYX(C4,GCF,MY,MX)
C     CLOSE (UNIT = 10)
      RETURN
  197 CONTINUE
C   * ------------------- SECTION 7 ---- FINISH OF SWEEP.
      RETURN
  198 CONTINUE
C   * ------------------- SECTION 8 ---- FINISH OF TIME STEP.
      RETURN
C***************************************************************
C
C--- GROUP 20. Preliminary print-out
C
   20 CONTINUE
      RETURN
C***************************************************************
C
C--- GROUP 21. Print-out of variables
C
   21 CONTINUE
C   * Make changes for this group only in group 19.
      RETURN
C***************************************************************
C
C--- GROUP 22. Spot-value print-out
   22 CONTINUE
C   * Make changes for this group only in group 19.
      RETURN
C***************************************************************
C
C--- GROUP 23. Field print-out and plot control
   23 CONTINUE
      RETURN
C***************************************************************
C
C--- GROUP 24. Dumps for restarts
C
   24 CONTINUE
      RETURN
      END
/*
//
```

B. COMPGRD

```
//COMPGRD JOB (2529,9999),'NIEBURG',CLASS=B,REGION=2000K
//*MAIN LINES=(99)
//CL EXEC FORTVCL,
//         PARM.LKED=('LET,NCAL,SIZE=(5000K,64K),NOXREF')
//FORT.SYSIN DD DSN=MSS.S1541.PHOENICS.SRC(GROUND),DISP=SHR
//FORT.SYSLIB DD DSN=MSS.PHOENICS.COMMONS.FORT,DISP=SHR
//LKED.SYSLIB  DD
//             DD
//             DD
//LKED.SYSLMOD DD DSN=MSS.S1541.PHOENICS.LOAD(GROUND),DISP=SHR
//
```

C. LINKEAR

```
//LINKEAR  JOB (2529,9999),'*CHAM',CLASS=B,REGION=7000K
//*MAIN LINES=(99)
//LINK EXEC PGM=IEWL,PARM='XREF,LET,LIST,SIZE=(2000K,256K),AMODE=24'
//SYSPRINT  DD SYSOUT=*
//SYSUT1    DD UNIT=SYSDA,SPACE=(CYL,(1,1))
//SYSLIB    DD DSN=MSS.S1541.PHOENICS.LOAD,DISP=SHR,MSVGP=PHOENICS
//          DD DSN=MSS.PHOENICS.EARTHL.LIB,DISP=SHR,MSVGP=PHOENICS
//          DD DSN=MSS.PHOENICS.RESLIB.LIB,DISP=SHR,MSVGP=PHOENICS
//          DD DSN=MSS.PHOENICS.SATLIB.LIB,DISP=SHR,MSVGP=PHOENICS
//          DD DSN=SYS1.VLNKMLIB,DISP=SHR,UNIT=3350
//          DD DSN=SYS1.VFORTLIB,DISP=SHR,UNIT=3350
//SYSLMOD   DD DSN=MSS.S1541.PHOENICS.LOAD,DISP=SHR,MSVGP=PHOENICS
//SYSLIN    DD *
  INCLUDE SYSLIB(GROUND)
  INCLUDE SYSLIB(GREX1)
  INCLUDE SYSLIB(MACDEP84)
  ENTRY MAIN
  NAME EARTHP(R)
//
```

APPENDIX E. PROGRAMS REQUIRED FOR COMPACTING FILES

A. PHOENX01 LOADLIB

```
//RATNER  JOB (2529,9999),'PHOENIX LOAD LIB',CLASS=A
//* STEP 1  RENAME CURRENT PHOENIX LOAD LIBRARY TO TEMPORARY LIBRARY
//STEP1  EXEC PGM=IDCAMS
//SYSPRINT DD SYSOUT=A
//SYSIN DD *
  ALTER MSS.S1541.PHOENICS.LOAD -
  NEWNAME(MSS.S1541.PHOENICS.LOADTEMP)
/*
//* STEP 2  ALLOCATE SPACE FOR NEW PHOENIX LOAD LIBRARY
//STEP2  EXEC PGM=IEFBR14
//DD1 DD UNIT=SYSDA,DISP=(NEW,CATLG,DELETE),
//       DCB=(RECFM=U,BLKSIZE=13030),
//       SPACE=(13030,(400,15,7)),
//       DSN=MSS.S1541.PHOENICS.LOAD
/*
```

B. PHOENX02 LOADLIB

```
//
//RATNER  JOB (2529,9999),'PHOENIX LOAD LIB',CLASS=A
//* STEP 3  COPY RENAMED OLD LOAD LIBRARY TO NEW LOAD LIBRARY
//STEP3 EXEC PGM=IEBCOPY
//SYSPRINT DD SYSOUT=A
//IN  DD DSN=MSS.S1541.PHOENICS.LOADTEMP,DISP=(OLD,KEEP)
//OUT DD DSN=MSS.S1541.PHOENICS.LOAD,DISP=(OLD,KEEP)
//SYSIN DD *
  COPY INDD=IN,OUTDD=OUT
/*
//
```

C. PHOENX03 LOADLIB

```
//RATNER  JOB (2529,9999),' PHOENIX LOAD LIB',CLASS=A
//* STEP 4 DELETE RENAMED OLD PHOENIX LOAD LIBRARY
//STEP4 EXEC PGM=IDCAMS
//SYSPRINT DD SYSOUT=A
//SYSIN     DD *
  DELETE MSS.S1541.PHOENICS.LOADTEMP                 NONVSAM SCRATCH
/*
//
```

D. PHOENX01 SOURCELB

```
//RATNER  JOB (2529,9999),'PHOENIX SOURCE LIB',CLASS=A
//* *******************************************************************
//* STEP 1  RENAME CURRENT PHOENIX SOURCE LIBRARY TO TEMPORARY LIBRARY
//* *******************************************************************
//STEP1  EXEC PGM=IDCAMS
//SYSPRINT DD SYSOUT=A
//SYSIN DD *
  ALTER MSS.S1541.PHOENICS.SRC -
  NEWNAME(MSS.S1541.PHOENICS.SRCTEMP)
/*
//* *******************************************************************
//* STEP 2  ALLOCATE SPACE FOR NEW PHOENIX SOURCE LIBRARY
//* *******************************************************************
//STEP2  EXEC PGM=IEFBR14
//DD1 DD UNIT=SYSDA,DISP=(NEW,CATLG,DELETE),
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=800),
//       SPACE=(23440,(200,30,7)),
//       DSN=MSS.S1541.PHOENICS.SRC
/*
//
```

E. PHOENX02 SOURCELB

```
//RATNER  JOB (2529,9999),'PHOENIX SOURCE LIB',CLASS=A
//* *******************************************************************
//* STEP 3  COPY RENAMED OLD SOURCE LIBRARY TO NEW SOURCE LIBRARY
//* *******************************************************************
//STEP3 EXEC PGM=IEBCOPY
//SYSPRINT DD SYSOUT=A
//IN  DD DSN=MSS.S1541.PHOENICS.SRCTEMP,DISP=(OLD,KEEP)
//OUT DD DSN=MSS.S1541.PHOENICS.SRC,DISP=(OLD,KEEP)
//SYSIN DD *
  COPY INDD=IN,OUTDD=OUT
/*
//
```

F. PHOENX03 SOURCELB

```
//RATNER  JOB (2529,9999),' PHOENIX SOURCE LIB',CLASS=A
//* STEP 4 DELETE RENAMED OLD PHOENIX SOURCE LIBRARY
//STEP4 EXEC PGM=IDCAMS
//SYSPRINT DD SYSOUT=A
//SYSIN    DD *
  DELETE MSS.S1541.PHOENICS.SRCTEMP                  NONVSAM SCRATCH
/*
//
```

APPENDIX F. PROGRAM "FORM09"

"FORM09" is required to format the PHOENICS output file "DF09" to a file that can be read by the graphics program "PHOTON".

```
//FORM09 JOB (2529,9999),'CHAM',CLASS=B
//*MAIN LINES=(20)
// EXEC FORTVCLG
//FORT.SYSIN DD *
C     PROGRAM FORM09
C
C  Increase PARAMETER settings if more variables or a larger grid
C  is required.
C
      PARAMETER(NPHIP=80)
C NB NXYMAX must be >= NZ and NX*NY
      PARAMETER(NXYMAX=20000)
      CHARACTER*4 NAME(NPHIP),MESS(10)
      CHARACTER*15 FILIN,FILOUT
      CHARACTER*1 ANS
      CHARACTER*10 ACCESS
      LOGICAL LBUF(10),STORE(NPHIP),DEBUG
      DIMENSION RBUF(NXYMAX),IBUF(10)
C
  100 FORMAT(1X,7I10)
  101 FORMAT(6(1PE13.6))
  102 FORMAT(1X,79L1)
  103 FORMAT(1X,19A4)
C
C  Reset DEBUG=.TRUE. to get error messages..
      DEBUG=.TRUE.
C
C  Set Logical Units...
      LUIN=9
      LUOUT=10
      LUBUG=6
C
C  Set File Names...
C  Name of unformatted restart file
C     WRITE(6,*) ' RESTART FILENAME?'
C     READ(5,'(A)') FILIN
C  Name of formatted restart file
C     WRITE(6,*) ' FORMATTED FILENAME?'
C     READ(5,'(A)') FILOUT
C
C  Direct access or sequential?
C     WRITE(6,*) ' DIRECT ACCESS (PHIDA) FILE?  Y/N'
C     READ(5,'(A1)') ANS
C     IF(ANS.EQ.'Y'.OR.ANS.EQ.'Y') THEN
C Version 1.4 default
C     ACCESS='DIRECT'
```

```
C     LENREC=256
C     ELSE
C Version 1.3
      ACCESS='SEQUENTIAL'
      LENREC=100
C     ENDIF
C     WRITE(6,*) ' DEFAULT LENREC? (100 V1.3, 256 V1.4) - Y/N'
C     READ(5,'(A)') ANS
C     IF(ANS.NE.'Y'.AND.ANS.NE.'Y') THEN
C     WRITE(6,*) ' LENREC? (WORDS NOT BYTES)'
C     READ(5,'(I)') LENREC
C     ENDIF
C  NBYTES is the number of bytes per single precision word.
      NBYTES=4
C Record length in bytes.
      LREC=NBYTES*LENREC
C
C  OPEN input file:
      OPEN(UNIT=9,FORM='UNFORMATTED',STATUS='OLD',
     1 ACCESS=ACCESS,IOSTAT=IERR,ERR=90)
          IF(IERR.NE.0) GO TO 90
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=1) (MESS(I),I=1,10)
      ELSE
      READ(LUIN) (MESS(I),I=1,10)
      ENDIF
           IF(DEBUG) WRITE(LUBUG,*) MESS
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=2) (LBUF(I),I=1,4)
      ELSE
      READ(LUIN) (LBUF(I),I=1,4)
      ENDIF
           IF(DEBUG) WRITE(LUBUG,*) (LBUF(I),I=1,4)
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=3) NX,NY,NZ,NPHI,(IBUF(I),I=1,6),LENREC
      ELSE
      READ(LUIN) NX,NY,NZ,NPHI,(IBUF(I),I=1,6),LENREC
      ENDIF
      NXNY=NX*NY
           IF(NXNY.GT.NXYMAX) GOTO 92
           IF(NPHI.GT.NPHIP) GO TO 93
           IF(DEBUG) WRITE(LUBUG,*) NX,NY,NZ
C
C  OPEN output file: FORMATTED, SEQUENTIAL and of FIXED RECORD LENGTH.
      OPEN(UNIT=10,FORM='FORMATTED',STATUS='OLD',
     1 ACCESS='SEQUENTIAL',IOSTAT=IERR,ERR=91)
          IF(IERR.NE.0) GO TO 91
      WRITE(LUOUT,103) (MESS(I),I=1,10)
      WRITE(LUOUT,102) (LBUF(I),I=1,4)
      WRITE(LUOUT,100) NX,NY,NZ,NPHI,(IBUF(I),I=1,6),LENREC
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=4) RINNER
      ELSE
      READ(LUIN) RINNER
      ENDIF
      WRITE(LUOUT,101) RINNER
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=5) (NAME(I),I=1,NPHI)
      ELSE
      READ(LUIN) (NAME(I),I=1,NPHI)
      ENDIF
C Set C36... names for variables 51 to NPHI for version 1.4, to avoid
C control characters etc| (Unless already stored)
      IF(ACCESS.EQ.'DIRECT'.AND.NPHI.GT.50) THEN
      READ(LUIN,REC=10) (STORE(I),I=1,NPHI)
      DO 6 I=51,NPHI
      J=I-15
       IF(.NOT.STORE(I)) THEN
        IF(I.LT.100) THEN
        WRITE(NAME(I),'(''C'',I2,'' '')') J
        ELSE
        WRITE(NAME(I),'(''C'',I3)') J
        ENDIF
       ENDIF
    6 CONTINUE
      ENDIF
      WRITE(LUOUT,103) (NAME(I),I=1,NPHI)
           IF(DEBUG) WRITE(LUBUG,*) (NAME(I),I=1,NPHI)
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=6) (RBUF(I),I=1,NX)
      ELSE
      READ(LUIN) (RBUF(I),I=1,NX)
      ENDIF
      WRITE(LUOUT,101) (RBUF(I),I=1,NX)
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=7) (RBUF(I),I=1,NY)
      ELSE
      READ(LUIN) (RBUF(I),I=1,NY)
      ENDIF
      WRITE(LUOUT,101) (RBUF(I),I=1,NY)
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=8) (RBUF(I),I=1,NZ)
      ELSE
      READ(LUIN) (RBUF(I),I=1,NZ)
      ENDIF
      WRITE(LUOUT,101) (RBUF(I),I=1,NZ)
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=9) (RBUF(I),I=1,NZ)
      ELSE
      READ(LUIN) (RBUF(I),I=1,NZ)
      ENDIF
      WRITE(LUOUT,101) (RBUF(I),I=1,NZ)
      IF(ACCESS.EQ.'DIRECT') THEN
      READ(LUIN,REC=10) (STORE(I),I=1,NPHI)
      ELSE
      READ(LUIN) (STORE(I),I=1,NPHI)
      ENDIF
      WRITE(LUOUT,102) (STORE(I),I=1,NPHI)
           IF(DEBUG) WRITE(LUBUG,102) (STORE(I),I=1,NPHI)
      NVAR=0
      DO 5 I=1,NPHI
      IF(STORE(I)) NVAR=NVAR+1
    5 CONTINUE
      IREC=10
      DO 10 K=1,NZ
      DO 20 I=1,NVAR
      IF(ACCESS.EQ.'DIRECT') THEN
      IREC=IREC+1
      NVREC=NXNY/LENREC
      IF(MOD(NXNY,LENREC).NE.0) NVREC=NVREC+1
      DO 30 IVREC=1,NVREC
      JF=(IVREC-1)*LENREC + 1
      JL=IVREC*LENREC
      JL=MIN0(JL,NXNY)
      READ(LUIN,REC=IREC) (RBUF(J),J=JF,JL)
   30 CONTINUE
      ELSE
      READ(LUIN) (RBUF(J),J=1,NXNY)
      ENDIF
      WRITE(LUOUT,101) (RBUF(J),J=1,NXNY)
   20 CONTINUE
   10 CONTINUE
           IF(DEBUG) WRITE(LUBUG,1900)
 1900 FORMAT(1X,' NORMAL STOP IN PROGRAM')
      GO TO 999
C Error trapping...
   90      IF(DEBUG) WRITE(LUBUG,1901)
 1901 FORMAT(1X,' ERROR IN OPENING INPUT FILE')
      GO TO 999
   91      IF(DEBUG) WRITE(LUBUG,1911)
 1911 FORMAT(1X,'ERROR IN OPENING OUTPUT FILE')
      GO TO 999
   92      IF(NXNY.GT.NXYMAX) WRITE(LUBUG,1921)
           IF(NZ.GT.NXYMAX) WRITE(LUBUG,1923)
 1921 FORMAT(1X,'SETTING OF NX*NY TOO LARGE; RESET IN FORM09 AND '
     1,/,1X,'RE-CREATE THE LOAD MODULE')
 1923 FORMAT(1X,'SETTING OF NZ TOO LARGE; RESET IN FORM09 AND '
     1,/,1X,'RE-CREATE THE LOAD MODULE')
      GO TO 999
   93      WRITE(LUBUG,193)
  193 FORMAT(1X,'SETTING OF NPHI TOO LARGE; RESET IN FORM09 AND '
     1,/,1X,'RE-CREATE THE LOAD MODULE')
  999 CONTINUE
C  CLOSE files ...
      CLOSE(LUIN,STATUS='KEEP')
      CLOSE(LUOUT,STATUS='KEEP')
      STOP
      END
//GO.FT09F001 DD DSN=MSS.S1541.PHOENICS.AUG90,DISP=(OLD)
//GO.FT10F001 DD DSN=MSS.S1541.PHOENICS.DF09C,DISP=(OLD)
/*
//
```

LIST OF REFERENCES

1. Salinas, D. and Kodres, C., *Modeling the Aerothermal Characteristics of Jet Engine Test Cells*, Department of Mechanical Engineering, Naval Postgraduate School, Montery, CA, October 1987.

2. Brunner, D. E., *Project Master Plan for Aviation Gas Turbine Engine Test Facilities (AGTETF)*, Naval Civil Engineering Laboratory, Port Hueneme, CA, March 1984.

3. Nicolaus, E. A., *Aerothermodynamics of A Jet Engine Test Cell Facility*, Master's Thesis, Naval Postgraduate School, Monterey, CA, September 1988.

4. CHAM of North America Inc., *PHOENICS Instruction Course Lecture Notes*, CHAM, Huntsville, AL, 1986.

5. Patanker, S. V., *Numerical Heat Transfer and Fluid Flow*, McGraw-Hill,1980.

6. Andrews, J. R. and Biblarz, O., *Temperature Dependence Of Gas Properties In Polynomial Form*, Naval Postgraduate School, CA, January 1981.

7. Rosten, H. I. and Spalding, D. B., *PHOENICS - Beginners Guide and User Manual*, CHAM Ltd., Wimbledon, London, England, October 1986

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, CA 93943-5002	2
3.	Professor David Salinas Code 069 Naval Postgraduate School Monterey, CA 93943	4
4.	June Favorite Code 0141 Naval Postgraduate School Monterey, CA 93943	2
5.	Dr. C. Kodres Naval Civil Engineering Laboratory Port Hueneme, CA 93043	2
6.	Commanding Officer NADEP Code 612-DBS Naval Air Station Jacksonville, FL 32212-0016	2
7.	LCDR Eric A. Nicolaus USCG Coast Guard MLC Atlantic Vessel Support Branch (VR-1) Governors Island, NY 10004	2
8.	LT Todd G. Ratner Department Head School Class 109 Surface Warfare Officers School Command Newport, RI 02841-5012	2
9.	Coastal Marine Research inc. P.O. Box 1109 136 Central Ave. Island Heights, NJ 08732 Attn: Wayne Sule	2
10.	CHAM of North America 1525a Sparkman Drive Huntsville, AL 35816	2

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93943-5002

✓

Thesis
R24353 Ratner
c.1 Parametric study of the
aerothermodynamics of a
jet engine test facility.

Thesis
R24353 Ratner
c.1 Parametric study of the
aerothermodynamics of a
jet engine test facility.

AMERICAN BINDERY
TOPEKA KANSAS

thesR24353
Parametric study of the aerothermodynami
3 2768 000 81847 0
DUDLEY KNOX LIBRARY